COMPARISON OF THE SPAGHETTI MADE FROM HARD RED WINTER WHEAT FARINA, HARD RED WINTER WHEAT FLOUR AND DURUM WHEAT SEMOLINA

by

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INTRODUCTION

Pasta products or "Macaroni Products," as they are called in Title 21, part 139 of the Code of Federal Regulations (4), are defined as "the class of food, each of which is prepared by drying formed units of dough made from semolina, durum flour, farina flour, or any combination of two or more of these, with water and with or without one or more of the optional ingredients."

The major advantages of pasta are that they are simpler to make and when they are dried, they can be stored for long periods of time with little or no deterioration (33, 31, 56, 30).

The use of wheat in the form of pasta is widespread thoughout the world with product characteristics differing widely in shape from nation to nation.

While the per capita consumption of pasta is in an increasing trend, supplies of durum wheat available on the world market have tended to fluctuate more than those of common wheat (33). In countries where durum wheats are scarce, and due to price and foreign exchange problems, the use of hard wheats or blends of hard wheats with durum wheats for pasta manufacturing is a common practice.

No quantitative evaluation of the quality of spaghetti made from hard red winter wheat (HRW) has been reported, but at present there are pasta manufacturers making their pasta products from hard wheat farina or hard wheat flour.

It is known that the uniformity of the particles is very important. But there is limited data available on the subject of granulation of the raw product over the cooking of the pasta. For this purpose pasta has been made from Commercial HRW Farina (-20W +40W), Commercial HRW Farina

(-40W+60W), HRW Flour from Farina (-20W+40W) and Commercial Durum Semolina as a control. The water absorption during cooking, the resistance to disintegration and firmness of the cooked spaghetti products of the above raw materials have been compared.

Also, work has been done on the production of pasta containing a food coloring "yellow No. 5" (a certified food color) for matching the natural yellow color of pasta made from Durum wheat. The colored pasta is not permitted here in the U.S., but in other countries is accepted. Nevertheless, since this food coloring is being used in beverages, bakery goods, pet food, dessert powders, candy, confections and cereals at present, its introduction to the pasta industry would not be a hard task.

This study was therefore designed to investigate:

1) Utilization of hard red winter wheat (HRW) for making spaghetti.
2) Incorporation of a coloring additive in HRW made spaghetti for matching the yellow color of durum wheat made spaghetti.

REVIEW OF LITERATURE

Historical Background

So far as we can learn, the first pasta products were made in China (58, 70, 71). It is not known really how they came to Europe, but according to a legend (70) an Italian explorer, Marco Polo, upon a return from China, first introduced a pasta product to the royal courts of Italy in the 13th Century. A major consideration was put on pasta because, a food which could be stored without deterioration for long periods of time was adequate to carry aboard ships for voyages of several months.

According to Schumacher (58), Germany was the first place pasta, mainly noodles, was manufactured on a large scale, and Italy was second to start production in Europe. However, Hummel (30) stated that Italy was the first place and then France and Germany. Rapid development in Italy was due to two factors, a) good hard wheat suited for pasta manufacturing was already being grown in the south of the country, and b) pasta products were dried outdoors, which was the only drying method known, and the climate, particularly around Naples, was best suited for this purpose.

Raw Materials for Pasta

Pasta products as defined by the Code of Federal Regulations (8) are defined as "the class of food each of which is prepared by drying formed units of dough made from semolina, durum flour, farina, flour, or any combination of two or more of these, with water and with or without one or more of the optional ingredients." The permitted optional ingredients are egg white, disodium phosphate, onions, celery, garlic, bay leaf, salt, gum gluten and concentrated glyceryl monosterate. For more information about these optional ingredients see Appendix 1.

Egg white, gum gluten and glyceryl monostearate are usually used to prevent disintegration and sticking together of canned products (31).

Milk macaroni, nonfat milk macaroni, vegetable macaroni (can be made of tomato, artichoke, beet, carrot, parsley or spinach), whole wheat macaroni, and wheat and soy macaroni are made in small quantities. Whole milk macaroni is rarely made because of possible rancidity of the butterfat and poor texture of the cooked product; however, when nonfat milk is used, the texture and keeping quality are improved (31).

When eggs are added to pastas, they become either egg macaroni or noodles.

The addition of enrichment, which includes thiamine, riboflavin, niacin and iron, in pasta products make those products become enriched macaroni or enriched noodle. Also, such products may contain Vitamin D, calcium and partly defatted wheat germ as optional ingredients.

Since there are so many shapes and sizes of pasta products, no official standard dimensions are available for most. Nevertheless, the Standard of Identity (8) makes certain definitions that are important to mention: a) Macaroni is the unit which is tube-shaped, and more than 0.11 inch but not more than 0.27 inch in diameter. b) Spaghetti is the unit which is tube-shaped or cord-shaped (not tubular) and more than 0.06 inch but not more than 0.11 inch in diameter. c) Vermicelli is the unit which is cord-shaped (not tubular) and not more than 0.06 inch in diameter.

Generally, it is recognized that milled products of durum wheat, which are semolina, durum granular, and durum flour, are the preferred raw materials for use in pasta products, and to a lesser extent, farina and flour from common wheats are used also (71). Hoskins (31) postulated that durum dough will extrude through a small hole at lower pressure than hard wheat dough. According to Irvine (33), although durum is the best type of wheat for pasta processing, almost any type of wheat may be used for this purpose. However, he states that for canning, durum wheats behave better than hard wheats. He also outlines that a number of other food products, other than wheat, may be added to the dough in the processing of pasta. The most common is egg, but adjuncts may be vegetables, soy flour, cassava flour, etc.

LeClerc (42) observed that macaroni-like products are made from materials other than wheat such as rice, corn and certain varieties of beans. Hoskins (31) also outlines that hard wheat flour and farina will make an acceptable pasta, but the color is not so yellow as the color of the durum product.

In countries like Brazil, Colombia, Portugal, and others, the use of farina or hard wheat flour instead of semolina for pasta production is a common practice. In these countries, the use of color additives and/or ingredients such as eggs are used to obtain a pasta with yellow color. In Brazil, according to Day (13), pastas are not made from durum wheat, and the farina sold for pasta manufacturing may contain up to 10% cassava flour or other nonwheat starch material.

Durum wheat differs from hard wheat in that it belongs to the species "Triticum durum" and hard wheat belongs to the species "Triticum aestivum" (7).

Nelstrop (56) stated that durum wheat is not suitable for the production of bread flour because it has a hard endosperm, a high ash content, a yellow color, and fairly strong, moderately elastic and extensible gluten. Compared with bread wheats, durum has a thinner bran skin with consequently higher proportions of endosperm. Gilles (25) also stated that durum wheat is characteristically higher in ash, lipid, sugar and carotenoid pigment content than bread wheat.

The evaluation of durum wheats has been more critical than other wheats according to Fabriani (21). The reason that he gives is that reasonably good bread and other products, such as biscuits, can be obtained with inclusion of adjuncts in the formula and processing adjustments for wheat of low-grade baking quality, whereas poor-quality semolina will not make good pasta.

Shuey (61) compared durum semolina and pasta products from various countries. The amounts of common wheat used to blend with durum wheat varied from 75 to 25%. He concluded that since the preference in tenderness of the cooked pasta varies from place to place, it is difficult to establish specifications for the requirements of raw material.

Role of Protein

According to Irvine (33), a high level of protein or wet gluten content is desired in semolina, because better cooking is normally associated with high protein levels. Walsh (68) stated that although protein content is not as important to durum quality as it is to bread wheat quality, adequate amounts of protein are needed for good cooking performance of pasta.

Holliger (28), making studies with durum and hard wheats, reported that gluten quality in the wheats he tested did not lead to extreme differences in the cooking behavior of the resulting spaghetti products, but the gluten quality played a more important role.

Kobrehel et al. (41) studied 17 samples of durum wheat varieties and they concluded that improving cooking quality by increasing protein content could cause the color deterioration of pasta products.

Walsh and Gilles (73) reported that protein composition was related to several spaghetti quality factors. High spaghetti firmness was associated with high glutenin, but low gliadin contents. High albumin and glutenin contents were associated with poor spaghetti color.

Sheu et al. (60) reported that interchange of gluten and water soluble fractions of hard red spring farina and durum semolina had a pronounced effect on pasta color and cooking characteristics. The difference in cooking quality in terms of cooked weight, residue and firmness were attributed primarily to the gluten fraction. But pasta color was affected by the gluten and water soluble fractions.

Reports of Dahle and Muenchow (12) stated that the removal of lipid or protein from spaghetti resulted in increased amounts of amylose in the cooking water. Also the removal of protein resulted in increased amounts of water being retained in the cooked spaghetti. But in general, the cooking quality of the spaghetti was more affected by the removal of protein than lipid.

Matsuo and Irvine (47) studied the effect of different types of gluten on spaghetti cooking quality. The gluten characteristics were measured using the farinograph, alveograph, and the Kosmino gluten stretch test. They concluded that protein quantity is not necessarily related to firmness in cooked spaghetti, but the kind of gluten quality has a more pronounced effect than amount of gluten. In a more recent paper, Matsuo et al. (52) reported that protein quantity has a marked effect on cooking quality of spaghetti. They also improved the protein quantity of semolina with adjuncts from proteins of rapeseed meal, fish protein concentrate, soy flour and egg albumin, as well as protein components from durum wheat, and the semolinas were processed into spaghetti. Their results showed that the most pronounced improvement in cooking quality was found with egg albumin and with glutenin; improvement was also found with gliadin, whereas proteins from other sources had little effect.

Work of Wasik and Bushuk (76) suggest that there are differences in protein composition (protein molecular-weight distribution) among durum wheat varieties of different quality. These differences appear to be related to the spaghetti-making quality, as it was possible to rank 14 varieties on their glutenin:gliadin ratio obtained from the gel filtration fractionation results in essentially the same order established by rheological and cooking tests.

Reports of Youngs et al. (80) referring to the processing standpoint, considered that the protein quantity in the semolina should not be too high or too low. Too high protein content tends to produce tough doughs, whereas low protein has a tendency to produce crumbly doughs during the mixing and kneading. They also considered the absorption as an important factor. Low absorption results in a stiff dough, producing a poor pasta color. On the other hand, higher absorption and the optimum absorption produce an optimum color. However, the higher the absorption, the greater the drying time required.

In recent studies made by Braibanti (9), they have suggested that the problem of stickiness of pasta is due to the lack of tenacity in the protein. When the pasta is cooked, starch granules swell in water and gelatinize. If protein reticulum is not sufficiently tenacious, the swelling of starch will break the protein structure, dispersing the starch in the water phase, resulting in what is called stickiness.

Role of Carbohydrates

Lintas and D-Appolonia (43) conducted investigations on the changes which occur in carbohydrate constituents as a result of the processing of semolina into spaghetti. Starch, water-soluble, and water-insoluble pentosans were isolated from semolina and the spaghetti processed from the same semolina. They found that the pasting properties, water-binding capacity, and starch damage value of the isolated starches were affected by the processing. Samples taken at different stages during the processing showed that some damage of starch took place during mixing and extruding, but particularly during drying. Measurement of the free sugars at different stages during processing revealed considerable differences in the amount of glucose and maltose present in semolina and spaghetti. These data are in agreement with the changes in starch damage.

It has been shown by Sheu et al. (60), that interchange of starch isolated from a durum wheat and a hard red spring wheat had little effect on cooking quality.

Dexter and Matsuo (15) hypothesized that since starch is the major component of semolina, then firmness in cooked spaghetti must, in part, be influenced by gelatinized starch properties. To prove the hypothesis, they used wheats, barleys, corns, rye, triticale, oats, and buckwheat as a source of starches to investigate the effect of starch properties on pasta dough rheology and spaghetti cooking quality. They found a wide range in mixing properties when starch and gluten blends' absorption was held constant at 36%, mainly attributable to variations in starch water absorptions. When the spaghetti made from those blends was tested, they found that waxy maize and waxy barley starches were detrimental to spaghetti cooking quality, but high-amylose corn starch appeared to impart a slight improvement in cooked spaghetti firmness.

Studies of Marshall and Wasik (46) stated that gelatinization of starch takes place gradually in an inward direction during the cooking of spaghetti. Therefore, the water penetration, and as a result cooking, was more rapid with lower levels of protein.

Role of Ash

A relation and a significant correlation coefficient between ash content and flour color reflectance readings with a M-500-A Agtron reflectance spectrophotometer was reported by Shuey and Skarsaune (62). They also claim that the relation between ash and the color reflectance readings is a suitable basis for an ash-prediction method.

Winston (79) stated that ash plays an important part in determining the quality of raw materials for pasta. He postulated that the higher the ash, the poorer the quality since the high ash indicated that more of the bran has been included in the milling. Bran in semolina is undesirable because it produces a brown pasta, which is more susceptible to checking and breaking during the drying process. It also tends to produce a poorly cooked product.

Ash content of wheat, according to Irvine (33), tends to vary quite widely and it is not a reliable index. Ash content is an environmental characteristic rather than a varietal one, and there is no evidence of relation between wheat ash and semolina color.

Abercrombie (1) stated that ash is not in the guidelines of raw material quality, but bran count or speck count is, and there is no one in this country buying semolina on its ash basis for pasta manufacturing.

Role of Color

Irvine (32) considers only the natural yellow pigmentation of durum as a criteria of quality to distinguish durum wheats from other classes of wheats as raw materials for pasta production. Furthermore, Irvine (33) reported that many years ago it was found that wheats from the south of Italy and North Africa made superior pastas than those produced from the European wheats; the former, durum wheats, were comparatively high in protein, and produced a yellow color pasta as opposed to the white or grayish product made from other wheat. Thus the tradition grew that if pasta was yellow, it was a superior product. This tradition is still current today, although circumstances which originally gave it validity no longer apply. Irvine continued stating that there are a number of other wheats which will produce good pasta, but which do not yield a yellow product.

Nelstrop (56) considers that the most influential factor affecting pasta color is the milling process. The manner in which the endosperm is broken is what he considers the most important. He states that if the endosperm is broken into a glasslike surface, it inhibits the distribution of water to the inside of the particle during the dough mixing. The dough consequently requires more kneading which can cause a breakdown of the gluten. On the other hand, if the particles are slightly crushed, there will be a more even hydration through the particle and the resultant pasta color is going to be brighter and yellow.

The yellow color of semolina is imparted by the carotenoid pigment xanthophyll (33). However, two factors may affect the subjective visual assessment of color: a) particle size and b) the amount of brown pigment present. The finer the semolina, the whiter the color. The brown pigments in semolina affect the yellowness and also the finished product. Some factors that give brownness in semolina are damage in durum wheat kernels, such as immature and frozen kernels (33).

The enzyme lipoxidase, which is responsible for bleaching the yellow pigments during the processing of pasta, varies with the variety of wheat being milled and with the extraction rate (33, 2). Semolina normally runs from 8 to 40 units of lipoxidase, but a high grade semolina from a high quality durum wheat will have a lipoxidase activity in the range of 10 to 20 units (33). Pigment losses are also affected by the concentration of unsaturated fatty acids in semolina, since this is the substrate for lipoxidase (33).

Irvine (33) stated that vacuum processing reduces pigment losses during the mixing phase and that this loss still occurs through the drying process. However, investigations made by Buhler (2) suggest that no significant differences in pigment loss occurred when pasta was manufactured with or without vacuum, because no press operates with an absolute vacuum and there is always oxygen to further reduce the color. Therefore, the better color of the products made with a vacuum process is just purely an optical effect because of the removal of air bubbles.

According to Irvine and Winkler (38), the yellow durum pigment is destroyed during macaroni processing and the destruction occurs during mixing and extrusion due to the enzyme lipoxygenase. The lipoxygenase activity varies with variety and environment according to Irvine and Anderson (37). They also found indications that the red wheat (SRW, HRW and HRS) have higher activities than white wheats and some varieties of amber durum wheat. More recent studies by Matsuo et al. (53) demonstrated that most of the pigment loss during pasta processing occurs during the drying cycle. On the other hand, studies made by Buhler (2) showed that there is no reduction of pigment content during drying operation. They attributed all the pigment losses to the mixing (up to 41% of original content) and to the pressing operation (up to 16% of the original content).

The measurement of pasta color goes back to 1937 when Fifield et al. (23) measured the yellow color of pressed disks of moist durum semolina with the Munsell spinning disk colorimeter. Their results showed a high correlation with semolina pigment content and visual measurement of semolina color. However, the spinning disk method lacked precision. Matz and Larson (55) worked the same problem and they tested several photoelectric instruments for measuring the color of semolina. Their findings were that the Hunter color difference meter, the Photovolt reflectance meter, and Densichron reflectance meter gave good results.

Matsuo and Irvine (48) reported differences in the reflectance spectra between yellow and brown macaroni, using the ten select ordinated method as described by Hardy (26). Their method was accurate, but was too time-consuming to be used for screening numerous samples. Then Walsh et al. (75) studied spaghetti color measurement with a tristimulus colorimeter. After some calculation, they were able to compare their results with Hardy (26) and they found that their method was rapid and that it correlated with visually tested samples.

The later report about spaghetti color was given by Walsh (66) who used a Zeiss Spectrophotometer and a Hunter Color Difference Meter. All three instruments were equipped with optical filters to measure the reflected light intensities. Good agreement between photoelectric reading and visual judgment of the color was obtained.

Dexter and Matsuo (16) demonstrated that pigment loss during processing of pasta is increased with increasing semolina extraction, resulting in decreased spaghetti pigment content. The spaghetti also became more brown and dull as semolina extraction increased. They also demonstrated that milling for coarser semolina granulation does not affect spaghetti cooking quality, but results in slightly improved spaghetti color.

Role of Particle Size

The Standards of Identity (3) define semolina as "the food prepared from grinding and bolting cleaned durum wheat to such fineness that, it passes through a No. 20 sieve, but not more than 3 percent passes through a No. 100 sieve." Also, it should be free from bran and germ, and its ash on moisture-free basis is not more than 0.92 percent. The same standard (3) defines Farina as "the food prepared by grinding and bolting cleaned wheat, other than durum wheat and red durum wheat, to such fineness that, it passes through a No. 20 sieve, but not more than 3 percent passes through a No. 100 sieve." Also it should be free of bran and germ, and its ash on moisture-free basis is not more than 0.6 percent.

The total moisture content for semolina and farina should not be more than 15 percent (3).

Different semolinas are produced by durum millers for the pasta industry. These are distinguished by the particle size and its distribution, but with the introduction of the continuous processing, the granulation uniformity is very critical, the raw material should be as uniform in size as possible to achieve uniform flow in the feeders and to have uniform water distribution in the dough (33, 31, 30). Fine particles will always have a tendency to absorb more water than their fair share, not leaving enough water for the complete hydration of the coarse particles, something that takes more time (33, 31). Coarse particles will not hydrate fully and will show up as white specks in the finished pasta (33, 31, 56, 30).

Hoskins (31) states that granulars and semolina are somewhat more desirable for use in a macaroni plant because they flow from bins in the continuous press more evenly and with less trouble from ridging in bin outlets. Besides, the water absorption of flour is greater than that of semolina or granulars so that flour products require more drying time than semolina products.

A typical granulation range for semolina as suggested by Abercrombie (1), could be as follows:

U.S. Sieve No.	%
30 W	0
40 W	20-28
45 W	20-30
60 W	30-40
100 W	10-15
Pan	Less than 3

Irvine (34) postulated that the best semolina was considered to be a coarse fraction with relative uniform particle size distribution; however, with the new continuous processing, finer semolina is now considered to be the most suitable (30). Granulations through a 40-mesh and over 80-mesh would appear to be most suitable for continuous processing (33) and through a 25-mesh and over 40-mesh are more suitable for batch processing (33) because the kneading is varied according to the needs of the dough. The advantage of coarser granulation will be that the doughs can be processed with minimum addition of water, making the drying easier (33).

Studies made by Wichser (77) revealed that particle size range for similarly milled flours was nearly the same, regardless of the class or variety of wheat; however, the distribution of the particles, according to size within this range, varied greatly.

Experiments with various blends of coarse, medium and fine semolinas made by Irvine (35), reported that a small percentage of coarse particles had a marked effect on rheological properties. However, blends of medium and fine particles alone showed little change in rheological properties over a wide variation in their ratios respectively. This evidence shows the importance of homogeneity of particle size and an optimum particle size being in the direction of a finer semolina.

A decrease in semolina and macaroni color scores, and a higher water absorption and ash have been reported with the decrease in particle size by Youngs et al. (80).

Harris et al. (27) suggest that since particle size has a marked influence on the visual semolina color score, the miller can influence and improve the color of his semolina product through judicious blending of various fractions consisting of different particle sizes.

Seyam et al. (59) said that different particle size distribution of milled semolina did not appear to affect the quality of the finished pasta product. They also said that millers have some flexibility in the range of the semolina particle size they may wish to grind without affecting the quality of the final pasta product. Furthermore, they reported that coarse semolina had more specks due to the large chunks of endosperm with the bran attached, and they concluded that the bran particles adhering to the endosperm did not separate readily during semolina purification. Other conclusions that they had were that with finer granulation there was an increase in water absorption, probably caused by the increase in starch damage. The cooking results of the different granulations reported to increase with finer granulation, but there were no significant differences in the spaghetti firmness scores due to granulation.

Studies made by Fernandes et al. (22) concluded that intermediate size granular millstreams appear to be the most promising for pasta production from bread wheat varieties on the basis that their physical, analytic and rheological data are similar to those of granular material of known pasta production capabilities.

Role of Dough Rheological Properties

Nelstrop (56) reported that the water absorption of the semolina must be such as to produce a dough with the optimum rheological properties for extrusion, but not slack enough to stretch during drying.

Irvine et al. (39) developed a farinograph method to assess rheological properties of pasta doughs and worked with farinograms using macaroni absorptions. They explained that there are two types of farinograms: those with a high tolerance index value, and those with a low tolerance index. They associated the high tolerance index values with good durum varieties, reasonably high protein content, and homogeneous particle size; low tolerance index values were associated with wheats other than durums, from low protein samples, from poor durum varieties, and from heterogeneous semolina. They also reported that rheological properties were also affected by several factors, such as wheat grade, variety type, protein content and environmental growing conditions.

Irvine (35) added that various attempts have been made to correlate the behavior of semolina doughs in continuous pasta processing equipment with techniques and measurements made to test rheological properties of bread wheat doughs. Nevertheless, there is little belief that the rheological properties of semolina doughs compared to bread doughs are very different because of the lower pasta processing absorption levels that are used.

In more recent studies by Matsuo and Irvine (51), they studied the missing characteristics of durum semolinas and classified them by farinograms into three types: weak, medium and strong gluten semolinas; they reported that increased gluten strength generally increased the width of the farinograph curve, and the dough was more tolerant to mixing. They explained that the assessment of rheological properties of semolina doughs was a good indication of spaghetti quality. However, it does not necessarily follow that the cooking quality of the spaghetti will be good because of desirable rheological properties; and the cooking quality is still the judgment used by the producer and consumer of pasta.

Scanning electron microscopy study of spaghetti processing, made by Matsuo et al. (54), found that when water is added to the mixing stage before dough formation, the structure characteristic of semolina begins to change to a more open structure. Concomitant with the dough formation, a jagged discontinuous protein matrix becomes predominant. Starch granules align along the direction of flow by the time the dough reaches the end of the extrusion auger. The protein matrix becomes more ordered as processing continues, but does not achieve gluten development. This is due to the fact that water used in pasta doughs is insufficient to hydrate gluten proteins. In addition to this, Dexter et al. (17), making a scanning electron microscopy study of cooked spaghetti, had suggested that differences in spaghetti-making quality are likely due to the manner in which the proteins withstand boiling water during cooking. Recent studies by Dexter and Matsuo (16) suggested that gluten breakdown cannot occur at absorption below 45% in durum semolina. For a series of wheats tested, they found that strong gluten wheats were found to achieve maximum gluten breakdown during mixing at higher dough water contents than were weak gluten wheats.

Pasta Quality

According to Hoskins (31), when pasta is cooked in boiling water, it should maintain its shape without falling apart or splitting and should cook to a firm consistency free from a slimy, sticky surface. The cooking water should be relatively free of starch and the product should be resistant to disintegration due to overcooking.

Because pasta products are made normally of durum wheat products, the yellow color produced by these wheats has become associated with good quality, which, in terms of consumer appeal, yellowness is an important quality parameter (31).

Studies by Matsuo and Irvine (47) in evaluation effect of gluten on the cooking quality have shown that gluten quality is the major factor determining cooking quality. However, as I mentioned before, Holliger (28) stated that the gluten quantity played a more important role.

Sheu et al. (60), working with the biochemical constituents of wheats, fractioned hard red spring farina and durum semolina into starch, gluten, water-soluble fraction and sludge. By systematic interchange of the various fractions, a series of flours were formed and pastas were made from the flours. Then, the pasta quality was evaluated, and they found that durum wheat gave superior color, higher cooked weight, greater water solubles and a lower firmness score then pasta made from hard red spring wheat. Furthermore, they reported that interchange of gluten and water soluble fractions had the most pronounced effect on pasta color and cooking characteristics.

On the other hand, interchange of starch and sludge fractions had no effect on color and only a small effect on cooking quality.

One of the earliest definitions of cooking properties of macaroni was given by Binnington et al. (11) in 1939. They defined the cooking properties of macaroni as the ability to resist disintegration upon prolonged boiling with water, coupled with a satisfactory degree of tenderness in the cooked product. More recent considerations have been made by Walsh (67, 69), where the quality of the cooked pasta, he states, depends upon several factors: how the product holds up to cooking; how much water is absorbed; the loss of solids in the cooking water; and in particular, the firmness or "bite" of the cooked pasta as he calls it. In previous work, Walsh et al. (74) found that cooked weight was related to the spaghetti firmness in the cooking test. However, according to Matsuo and Irvine (47), such factors as cooking water residue and water uptake are not clearly related to the quality of the cooked spaghetti as judged organoleptically.

There is a general agreement about the appearance of dry pasta; it should be smooth, free from cracks and specks, and have a bright yellow color (30). But, the cooking test is probably the most important test on pasta products. The amount of swelling or water absorbed during cooking is measured by weighing the product before and after cooking. The weight increase is due to water absorption. Loss of solid to cooking water and the firmness are the most important of all characteristics between the cooking test. The cooking water is evaporated to dryness to measure the amount of solid dissolved in the water. In general, it is accepted that for plain macaroni products, the solid substance left in the cooking water should be 6 percent or less for a very good, up to 8 percent for an average, and 10 percent or more for a bad pasta (31, 30).

There are various reports about instruments for measuring the firmness of the cooked pasta. Bennington et al. (11) used the breaking-strength apparatus for evaluating cooked macaroni products; it was adapted from a fruit and vegetable tester. The sample is compressed by using a plunger, and breaking-strength is measured as the time to break the sample. In this test, it appears that the breaking time is associated more with variations in internal structure than with differences in wall thickness and diameter, and the variability of the test is rather high.

Matsuo and Irvine (50) described an apparatus for measuring the tenderness of the cooked spaghetti. The apparatus was designed with a cutting edge, to which an increasing force could be applied and, as the strand of spaghetti is sheared by the applied force, the movement of the cutting edge is measured and recorded. The resulting curve was interpreted in terms of rate of shear and designated as tenderness index. They reported that soft samples yield high values of tenderness index, while firm ones give low values.

Later on, Matsuo and Irvine (49), in an attempt to obtain a better evaluation of the cooked spaghetti, adapted the tenderness testing apparatus adapted to measure parameters related to chewing in addition to the tenderness index. They considered chewing as essentially a compressing or squashing from which one characterizes the product as doughy, mushy, or "al dente." To carry out this test, the cutting blade of the apparatus was replaced by a blunt-edge blade for compression. A fixed load was applied to the end of the beam on top of the rod connected to the blade; the load was removed after 15 seconds. This method of assessing cooking characteristics has been used in evaluating new durum varieties, in comparing domestic and foreign varieties, and in studying the effect of various factors associated with quality.

Holliger (29) made studies with a BUHLER TLU-101 laboratory tester. With this equipment, the spaghetti samples are loaded by purely mechanical means (bending or elongation as a function of the force applied). The bending or stretching response is recorded on a double scale on graph paper. The mechanism is designed in such a manner that increase in force is recorded uniformly on the diagram, whose results can be recorded in series and compared with each other. The results provide information on the strength of the products, and thus, on their quality.

Walsh (67, 69) developed a method for measuring the firmness of cooked spaghetti with an Instron Universal Tester. The amount of work required to shear a cooked strand of spaghetti with a Plexiglas tooth was used as a measure of spaghetti firmness. The measurements were compared with taste panel data and statistical analysis of the data was performed. The analysis showed that the shear test had a positive correlation with the taste panel scores. Furthermore, the shear test was more rapid and much more convenient than the taste panel method.

More recently, Vorse and Larmond (65) proposed a test that they considered to be better. To apply the test, the rate of shearing must be constant as in any other tests, but it has a multiblade shearing cell that measures the force to shear the sample at 100 places. The cell has been arranged to fit the Ottawa texture measuring system, and it produces a single numerical value (the maximum force), which is related to consumer reaction, and is sensitive to changes in texture owing to varietal differences or processing methods.

A high degree of translucency has traditionally been considered one of the attributes of high quality dry macaroni products, according to Irvine and Anderson (36). They studied pressed doughs under the microscope, finding that air incorporated during the mixing, and the degree of pressure applied to the dough in processing, had an effect on opacity, which appears to be largely a function of the number and size of the air bubbles in the finished product. They also tested the effects of mixing the doughs under oxygen, air and nitrogen, and they found that the solubility of the gas in the dough has a marked effect on the number of bubbles in the finished product.

Smith et al. (63) suggests that with other conditions constants high pressures and long pressing times result in fewer and larger bubbles. A short mixing time reduces the number of air bubbles occluded by the dough. Higher absorption increases the amount of gas dissolved in the dough and decreases the internal pressure of the dough; therefore, both effects should reduce the number of bubbles and improve the translucency of the pasta.

Manufacture of Pasta Products

History:

At the beginning, pasta products were all home-made. The first small pasta industry was developed in Italy, and about 1800 the first mechanical devices for pasta manufacturing appeared also in Italy (30). These were very unrefined and inefficient. Then, by 1860 more elaborate machines were developed, most of them driven by animal power. But the popularity of pasta continued to increase and this called for more efficient equipment manufacturing. These were subsequently developed in Italy and France, later in Germany (30).

At the beginning of the 1900's efficient equipment comprised of mixers, kneaders, hydraulic extrusion presses and drying cabinets became available.

No changes were made for about 30 years, but in 1934, the first continuous extruder automatic press was developed, and started to replace the batch process equipment. Similar presses were built later in the U.S.A., and today all new equipment used for pasta extrusion is of the continuous type.

Manufacturing Process:

Pastas are obtained by mixing semolina, farina, flour, or any combination of two or more of these, with water and kneading this mixture for a short period of time into a homogeneous mass. This mass is then extruded under pressure through a die or mould. According to the size and shape of the holes in the die, the extruded pasta is called spaghetti, macaroni, elbows, alphabets, shells, stars, wheels, rings, vermicelli, etc. The extruded pasta then goes to the dryer in the shortest possible time, and with a minimum of handling. Freshly-made pasta is soft and delicate. Once the pasta has been dried, it can be handled easily for packing and stored for long periods of time. Pastas have excellent keeping qualities when they are dried to about 13% or less water content (31, 30).

Rolled pasta products, like noodles and the pasta for ravioli, are generally obtained by preparing a coarse sheet of dough on a special die with a continuous extrusion press. The sheet is then rolled out on a dough breaker to a sheet of desired size and thickness. Next, it is cut on cutting rolls into ribbons for noodles or the finished sheet can also be fed into a stamping machine for other forms like bows.

Batch Processing

Batch processing is the older method of pasta manufacturing. It is still used to a minor extent in underdeveloped countries. The batch system requires a great deal of handling and man power.

The first step in this operation is the doughing or mixing. Here the ingredients (semolina, farina or flour) are mixed with a suitable amount of water to make a dough. Hummel (30) and Winston (78) suggest the use of 25 lb. and 26 to 30 lb. of water respectively for 100 lb. of raw material. The exact proportion of water used depends upon the quality of the raw material, the type of product to be produced and the manufacturing equipment to be used. It is said that dough for long goods (like spaghetti) required less water than dough for short goods (like elbows).

Sometimes, a small amount of salt is added during the mixing process according to Winston (78).

In pasta manufacturing, it is very important that the proportion of raw material and water be constant. When using batch mixing, each batch is weighed on automatic scale, which is filled from the bins. Depending on the size of the mixer, batches of 50 to 150 Kg. (110 to 330 lb.) are weighed at a time in commercial production.

The water normally is measured by volume, using a tank provided with a scale. The water temperature ranges from 70 to 110^{o}F (21 to 44^{o}C) according to Winston (78). As a rule, the water is drawn from a warm water tank and partly from the cold water main.

During water incorporation in the mixer, the water has to be distributed evenly. If this does not occur, the even distribution will have to be obtained in the kneader; this means more work for this machine. In many cases, according to Hummel (30), the kneader will not be able to get the water evenly distributed without excessive work, and this has a tendency of weakening the strength of gluten, and when using semolinas, the finished product may have an uneven color. The strength of the gluten is what enables the pasta products to keep their shape when cooked, and prevents them from becoming paste.

During mixing, it is necessary for the raw product and water to remain together long enough for the water to be absorbed and each particle to swell properly. If this is done, kneading the mixture of water and raw material into a homogeneous dough will be done easily.

Mixing does not interfere with the strength of the gluten, but kneading tends to weaken the gluten; therefore, it should be reduced to a minimum. Gluten loses its strength when it is severely kneaded in the presence of water and heat (30).

From the mixer, the mixture of raw product (semolina, farina or flour), sometimes known as gramola, is transferred to the kneader (see Fig. 1). The function of the kneader is to produce a dough of good uniform texture and color without destroying the gluten strength.

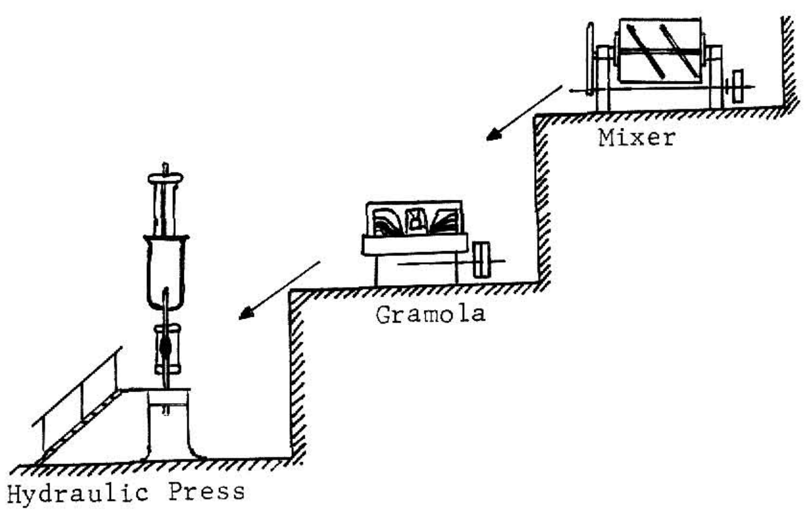

Figure 1. Working by gravity with batch mixers. (30)

When the dough is ready, it is removed from the kneader and placed in the extruding press as quickly as possible. If this is not done fast, superficial drying could occur, which would produce hard particles of dough that, when they are extruded, are retained in the holes of the die giving a rough surface appearance.

The extruding presses can be of two types. The "screw type" operates slowly and is not very efficient, but since the advance of the piston is very regular and independent of the consistency of the dough, it produces a very regular product. The other type is the "hydraulic type." In this type the pressure required to extrude the product depends on the hardness of the dough, its temperature, extrusion speed, and the die. Warm dough, a soft or moist mixture, needs low pressure; on the other hand, cool dough, a hard or dry mixture, needs high pressure. A high extrusion speed goes with a higher pressure, and in a similar way, low speed goes with a lower pressure. The extrusion pressures range between 100 and 200 Kg. per cm^2 (30). This explains why this type of extrusion presses are so big, strong and expensive.

The two above extrusion presses can be found with one or two pots. The two pot press has a larger capacity because while one pot is being compressed, the other is being charged.

One of the problems of the extrusion press is the air incorporated in dough, which sometimes appears in the extruded pasta. And here is where the extrusion under vacuum, a process familiar to the brick and tile industry, was proposed for getting a better and more homogeneous product.

For the production of "long goods", the screw and hydraulic presses are always vertical presses. The product is allowed to extrude a little over three feet in length, then it is cut with a knife and the pasta is placed on sticks and distributed evenly by hand.

For the production of "short goods" a rotating knife, using a variable speed drive, drives the knife which can be set to cut the pasta to a desired length. To get a wider range of length of cuts, knife-holders, which can hold two or more knives, may also be used. This is something that has not changed with the years and is still used for the most modern continuous extrusion presses.

Continuous Processing

Until about 1935 (30) all pasta products were made using the batch process. But, in 1934 (30) Buhler and Braibanti supplied their first continuous extrusion press which kneads the dough and builds up the necessary pressure with a worm. All the continuous extrusion presses now available in the market use a rotating worm or auger to extrude the dough.

a) Blending: For feeding the continuous extrusion press, a uniform blend of raw products (farina, semolina or flour) and water is required. To produce a uniform blend, the proportions of raw product and water have to be constant. To achieve this purpose, some manufacturers of equipment use volumetric feeders and some others use gravimetric feeders. On small feeders of the belt type, the flow is regulated by increasing the speed of the belt, while with larger units the sections that move the product are regulated and the belt is kept constant. Other equipments uses worm conveyors and the speed of the conveyor is regulated.

Other types of feeding equipment are vibrators. In this case, the amount of feed is regulated by changing the amount of vibrations. Hummel (30) states that the flow delivered by vibrators is very uniform and can be regulated very precisely. The vibrations are produced by electromagnets in the frequencies of 50 to 60 oscillations per second.

The required quantity of water is fed into the mixer with the help of: a pump with variable stroke adjustment; or a water wheel, in which case the water is regulated by the speed of the wheel or the depth of the water in the container where the wheel is immersed; or regulating the flow of water through a jet and it is adjusted by changing the pressure; or with constant pressure and a needle valve. The last two are the most common types.

One important point which must be taken care of is that the flow of water must be delivered into the semolina and not through the mixing shaft, paddles or mixer trough to prevent the product from sticking to them.

Some manufacturers of equipment can equip their blending system with an alarm if the supply of any raw material fails to be incorporated in the mixer.

b) Mixers: There are two types of mixers used for the continuous extrusion presses. One is the single shaft and the other is the two parallel shaft (or double shaft mixer) mixer. The advantage of the double shaft mixer over the single shaft is that it can be filled almost to overflowing and give more time to the raw material granules so that they can obtain their water share. On the other hand, the single shaft mixer should not be filled more than half.

The rotation of the mixer is not important for the single shaft mixer, but for the double shaft mixer, the rotation should be one by which the mixing blades dive into the mix along the trough wall, and work out of the mixer in the center. This not only gives uniform mixing, but keeps the trough wall clean.

c) Vacuum Chamber: Vacuum is an important factor in the production of pasta. It was first placed in the industry in 1950 by Buhler (58). The vacuum has to be done with a vacuum pump that is strong enough to provide the vacuum for the inevitable air leaks. The usual vacuum is 60 to 80% (30) of the atmospheric pressure. According to Hummel (30), the presence of vacuum during extrusion gives:

- better texture.
- smoother product and clearer color.
- a specific weight which is about 3% higher.
- reduced presence of air bubbles which reduces the specific weight and increases the transparency of the finished product.

Hummel (30) also states that vacuum does not alter the cooking qualities of pasta and does not have an influence on the way they dry, but Hoskins (33) stated that it does have an effect. Hummel continues with the statement that vacuum reduces slightly the output of the extrusion press; therefore, if the power required for the vacuum is taken into consideration, the total power required is practically the same as for the extrusion press working without vacuum.

In general, vacuum disadvantages are of less importance than its advantages. As a result, today all pasta manufacturers use the vacuum.

The application of vacuum can be done in different manners. Some constructors of equipment apply the vacuum to the mixer chamber, this requires that the ingredients be fed through an airlock. Other manufacturers place a small chamber under vacuum between the mixer and the worm; the blend is used to provide the airtight lock.

d) Extrusion Worm or Auger: The worm kneads the mix, which has been prepared in the continuous mixer, into a uniform and homogeneous dough. At the same time, it builds up the necessary pressure for extruding the dough through the kneading plate and die.

The pitch of the worm may be the same over the whole length, or it may be divided into two or three sections with different pitches. The worms are made mainly of stainless steel and bronze (30).

The pressures during extrusion are not as high as the batch processing presses. The dough on a continuous extrusion press is softer, even if the same proportion of water is used. This is because as soon as the dough has been kneaded, it is plastic material and it is extruded. There is not time for the dough to cool down or dry as in the case of the batch processing.

Pressures of 100 to 120 Kg/cm^2 are average. The higher pressure is only obtained when dry doughs are extruded. This low pressure compared with the batch process made a good impact in the development of the continuous press because high pressures have a detrimental effect on the gluten of the raw product and this will be shown in the cooking quality of the product.

In commercial extruders, the diameter of the worm may vary from 120 to 200 mm., and the speed of the worm may vary between 20 and 40 RPM.

The worm turns inside of a steel cylinder which is fitted with grooves for preventing the dough from slipping. The cylinder or barrel is water packeted to warm up the equipment at the beginning and cool down or dissipate the heat produced during extrusion. The temperatures are held between 40 to 60^{o}C (72), but never above the gelatinization temperature.

The worm never should be run in an empty cylinder as this will cause wear on the cylinder and worm. When the product is around the worm, it keeps the worm and cylinder separated from contact.

e) Kneading Plate: Kneading plates are necessary on the press for a uniform mass before it is extruded. Kneading plates may be placed one at the end of the cylinder head and the other, if required, just above the die. The number of kneading plates varies with the extrusion press.

One important point is that kneading not be exaggerated, it is detrimental to the quality of the gluten (30).

f) Extrusion Head or Cylinder Head: The cylinder head is the place of attachment between the extrusion worm and the die. The cylinder head diverts the horizontal flow of kneaded dough to the vertical position for its extrusion thru the die. The cutting knives and initial ventilation systems are also attached to the cylinder head sometimes.

The cylinder head in commercial size equipment is made in such a way that water can be circulated for heating or cooling the head. The only purpose of this is to keep the same temperature that the dough had in the extrusion worm or auger.

g) Die: In order to give a shape to the dough, the product has to pass through a die. Until about 1955, all pasta dies were manufactured almost exclusively of bronze alloys (18). Bronze is a material that is easy to machine, has good resistance to corrosive effects of dough and water, and obtains a high polish very easily.

Stainless steel dies are also used, but they are more expensive due to the fact that stainless steel is more difficult and expensive to machine. Hummel (30) and Hoskins (31) describe stainless steel dies as a not too common or not well accepted material for pasta product. They mention that they produce a product with poor texture and color, due to the fact that stainless steel is a poor heat conductor; therefore, the heat produced during the extrusion is not well dissipated.

Teflon lined dies were used sometimes in pasta extrusion. The products produced had a very good appearance, but Hummel (30) and Hoskins (31) stated that the surface of the product was so smooth that during cooking, water penetrates more slowly into the Teflon product and the product has the tendency to become soft before the interior has been thoroughly cooked.

After the above experience, a combination of 50% bronze and 50% Teflon was used, and it is claimed that this combination produces a product like the one extruded thru a Teflon die, but with the bronze cooking quality; in addition to this, Teflon has increased die lifetime (19).

For commercial scale extruders, the dies for "long goods" are long narrow dies, while for "short goods" the dies are round shaped.

The dies' perforations have a fairly long cylindrical part, starting with a larger diameter and ending in a small section, which gives the shape of the pasta. The dies for manufacturing spaghetti are very simple to make, and they become more complicated and expensive when the production of other shapes like numbers or letters is required.

For the manufacturing of hollow pasta, the introduction of a pin in the middle of a hole is necessary. This pin must be accurately centered if a straight macaroni of uniform thickness is required. On the other hand, if an elbow macaroni is wanted, the pin is slightly eccentric to give the dough a chance to flow faster on the side where the clearance is greater.

The short goods are cut on the die by a rotating knife, and to prevent them from sticking together, an air current is essential as the product leaves the die.

If a hollow product is not cut on the die, the hole may be closed by the knife.

For the design of dies, Hummel (30) stated that with a continuous extrusion press, dried pasta will be about 10% smaller in diameter than the hole of the die.

A die manufacturer (18) suggests that dies be returned to the maker for reconditioning at regular intervals of three to six months. This will ensure trouble-free operations and maximum output. The surface of the holes with time becomes rough and it has to be repolished.

Dies have to be cleaned from time to time, and never should there be pieces of dough because eventually souring will take place and the resulting acids will attack the bronze surface, causing pitting which impairs quality of the finished product (31). Furthermore, any impurity in the die will have a tendency to produce a rough surface pasta.

When cleaning a die, do not make any attempt to clean the die holes with metal scrapers. The metal scrapers will scratch the polished surface of the holes.

Dough never should be left in the die to dry; if it can not be cleaned immediately after having dismounted from the extrusion head, it has to be soaked in running water.

The die washing machines consist essentially of a pump, pushing water at high pressure through jets against the die. Pressures of 25 Kg/cm^2 (30) are recommended, lower pressures will not have enough impact in cleaning a die. Hoskins (31) recommends soaking the dies after washing in neutral mineral oil, as this will prevent any pitting and corrosion from occurring.

h) Cutters: The production of "short goods" requires a variable speed running knife over the surface of the extrusion die. With the variable speed, you can cut the product to any length. The cutters consist essentially of one or more arms that rotate with a shaft, each arm is provided with a knife blade that cuts the product as it is being extruded. At the same time the product is being cut, a fan blows air to the die and the product to prevent the "short goods" from sticking together.

The cutters for long and narrow dies are different. Normally they are two rotating knives below the die which move the die all the way from one end to the other. For this type of cutter, a strong ventilation is also required.

i) Spreader and Shaker: The spreader is the machine that is used for placing the "long goods" products on sticks before they can be dried. Before, this operation used to be made by spreading the "long goods" by hand; from a hygienic point of view and larger extrusion capacity, the hand spreading is not used any more in the continuous extrusion manufacturing. In the batch processing, it still is common due to their low scale capacity.

The shakers are the machines that distribute the "short goods" on the screen of the dryers. They carry the "short goods" and spread them out across the drying screen to a depth of approximately ½ inch. However, the dryer, as it is conveying the product to the end, is increasing the depth to about 1½ inch.

Drying of Pasta Products

Drying of pasta products has as its prime objective the removal of moisture from the initial point to a level of 10 to 13%, so that the pasta will be hard, retain its shape and will store without spoiling (31, 78). Upon extrusion from the press, pasta is a soft, plastic product containing approximately 31% moisture. This wet product has to be dried to obtain a hard product which will not support the growth of mold, yeast or other spoilage organisms (31, 72).

Too rapid removal of the moisture will cause checking or cracking of the product. On the other hand, too slow removal of moisture may permit stretching of the long goods on the sticks, or souring, or mold growth (70, 71, 31, 72). Therefore, to achieve proper drying, the rates of drying have to be determined by adjusting air circulation, temperature, humidity of the air and product (31, 30). The problems in selecting a drier and setting the proper temperatures and relative humidity are similar regardless of the design of the drier.

The drying of pasta, as described by Walsh and Gilles (72), depends on the hygroscopic equilibrium moisture content, the free moisture and the shape and size of the product to be dried. If M_1 is the moisture content of the product at equilibrium with the atmosphere at a specified relative humidity and M_2 is the difference between equilibrium moisture and the actual moisture content M_3, then $M_2 = M_3 - M_1$. What this is, according to Hoskins (31), is that if a hygroscopic material such as pasta product is placed in a stream of air of given temperature and humidity, it will gain or lose moisture until it reaches a constant percentage of moisture which is called the equilibrium moisture. In the case of pasta products, the raw material is a complex, organic system containing starch, protein and other materials which change their properties according to the variety of wheat used, growing conditions, milling procedures, percentage of protein, previous drying conditions, and many other factors (31, 30).

Data obtained by Early (20), by drying pasta to a constant weight in a laboratory drier, with close control of temperature, humidity and air circulation at a temperature of 90°F, are shown in Table I. Hummel (30) did the same experiment and he plotted the results in a chart (see Fig. 2).

Pasta drying, as described by Donnelly (19), is an operation which uses a preliminary drier to quickly dry the product surface immediately after extruding. Pre-drying case-hardens the surface, so that the pasta pieces will not stick together. The interior of the product remains soft and plastic. The final drier is used to remove the bulk of the moisture from the interior of the product, but it is essential that the products be dried with a drying cycle tailored to meet the requirements of each product. An example of a drying cycle that has been successfully used for long goods was reported by Donnelly (19) and he explained the process as follows:

The pre-drier exposed the product to air at 150°F for 1½ hours at 65% relative humidity and lowered the moisture content of the pasta from 31 to 25%. The pasta is still quite pliable, so that rapid predrying does not set up stresses which would result in cracking or checking. The product then enters the final drier, which has several zones or chambers in which the relative humidity can be varied, with the temperature held constant at 130°F. The first stage of the final drier holds the product for 1½ hours at 95% relative humidity. This is called the "sweating" or rest period, where the product is equilibrated with high-humidity air. In the second zone of the drier, the product is exposed to a relative humidity of 83% for four hours, after which the moisture content is about 18%. Additional moisture is removed in the third zone of the drier, where the product is held for eight hours at a relative humidity of 70%. Finally,

Table I

Equilibrium Moisture of Macaroni at 90°F (Early (20))

Relative Humidity (%)	Equilibrium Moisture (%)
90	22.0
80	18.2
70	16.0
60	13.9
50	12.1
40	10.5
30	8.8
20	7.0
10	4.9

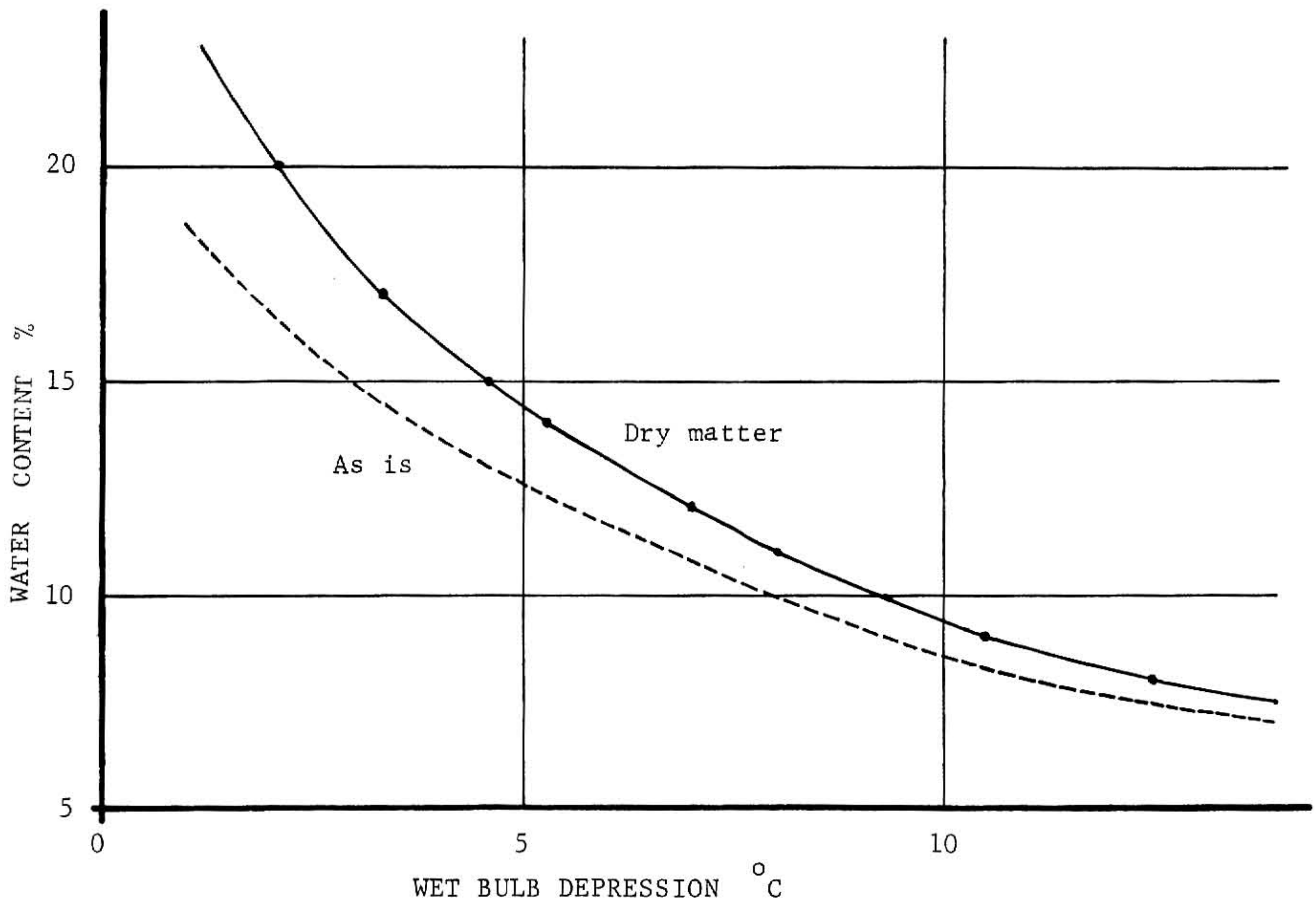

Figure 2. Equilibrium Water Content of Macaroni Products. (30)

the product is removed from the dryer and cooled to room temperature. According to Donnelly (19), if the drying cycle is successful, the product will be hard and flexible, so that it can bend to a considerable degree before breaking. If it has not been dried properly, it will be rather soft and tend to crumble quite easily. But the true test of drying is to find a product free of checks a week after it has left the drier.

Investigation in the use of microwave drying has been done and it will undoubtedly have a large impact on the pasta industry in the near future (40). This drying process has been successfully achieved with short goods on a commercial basis, but it has not been commercially successful with long goods up to this point. The major advantages of microwave drying are space savings, reduction in drying time and low plate counts. The drying time for short goods in conventional driers is 8-16 hours versus 1½ hours for microwave (19). In addition, some microwave dryer makers claim that there are color improvements, but the important part is that microwave requires ¼ of the floor space than that of conventional driers, which saves about 45-50% energy, greatly reducing total microbial counts (10).

During drying, pasta products develop their final color and texture. They should not warp or crack during the drying period, and they should not crack after being packed and ready for sale. They must not be allowed to sour or show too much acidity, and they must develop the clear yellow color (30).

As all these factors are to be taken care of, the pasta product manufacturers always used to be expected to have a man of wide experience (30); however, in recent years, it is possible to rule out the human element and to make perfect drying possible by any conscientious operator (30).

Until the beginning of the 20th century, it had been common practice to dry pasta products either in the open or in large drying chambers (30). The open system was possible only in countries where the climate was suitable (like the south of Italy). But with drying chambers, pasta can be worked in all countries.

The drying at present time can be done in two ways: batch drying and continuous drying.

a) Batch Drying: Batch drying is applicable to batch press processing. It requires a lot of man-hour operation and it is not used too much. For the batch drying, large chambers with travelling fans were used. These large chambers were replaced by small drying chambers and cabinet driers (30).

The conventional drying process, working in batches, divides the drying into three stages (30): pre-drying, softening period or sweating period, and final drying.

As the product leaves the die of an extrusion press, it is, as a rule, soft and warm, and has a tendency to stick together. Therefore, all extrusion presses are equipped with a fan blowing a current of air on to the product as they are extruded. This aeration is necessary to make the handling of pasta possible and to keep the die and cutting knife dry. From the die, short goods should go to the pre-drier in the shorter possible time, and with a minimum of handling. When possible, they should fall straight from the die on to the pre-drier. Freshly-made short goods are soft and delicate until they have been subjected to the pre-drying. After they have passed the pre-drier, they may be handled without difficulty (30).

Long goods must be spread on sticks before they can be dried. These sticks are hung on wagonettes or trolleys, and wheeled into the drying cabinet. This cabinet is fitted with a fan which circulates the air inside the cabinet. Air heaters may be built into the air circuit to heat the air. The air should travel vertically to give long goods a uniform pre-drying from top to bottom (30). Blowing the air from bottom to top results in too much agitation of the long goods. Blowing the air horizontally through the long goods will produce bent goods.

As short goods leave the pre-drier, they are carried into the drier for the final drying operation. The trays are piled into wagonettes, which are then wheeled into the cabinet drier. Alternatively, the trays may be inserted directly into the cabinet driers without using wagonettes. For long goods, the wagonette has to be used and it has to be wheeled into the drier.

Inside the drying chambers, the air may be circulated according to two different patterns. With one method, the trays form a vertical pile and the air is circulated vertically through the whole pile, flowing through all the trays in succession (see Fig. 3). When drying short goods, it is necessary with this system, to alternate the direction of the air flow, for instance, by changing the direction in which the fan revolves. If this is not done, the goods receiving the fresh air dry more quickly than the goods receiving air that has already flowed through the other trays (30).

The other method is arranged in such form, that air flows horizontally and all the trays are dried under the same conditions (see Fig. 4).

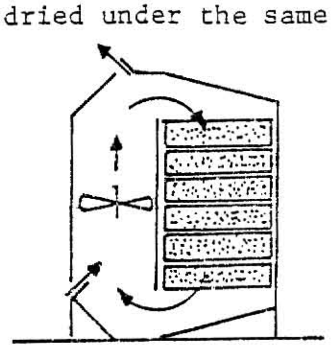

Figure 3. Diagram showing how the air is circulated vertically through the pasta trays inside the drying cabinet for short goods. (30)

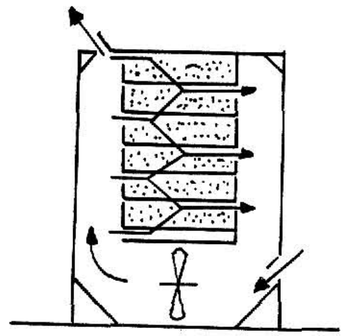

Figure 4. Diagram showing how the air is blown horizontally through the pasta trays inside the drying cabinet for short goods. (30)

For long goods, the drying of air circulation can be vertically (Fig. 5) and horizontally (Fig. 6). In this case again, the horizontal is better, but also requires that the air flow be alternated (30).

Pasta driers utilize a built-in thermostat to regulate the temperature, and a built-in hygrostat to regulate the humidity of the drying air. The thermostat acts on a valve governing the steam going to the air heater, while the hydrostat regulates the humidity by opening and closing the admitting and exhausting air valves in the drier (30).

At first, the pasta products are dried in warm, moist atmosphere with the fresh inlet valve open. Then with heating on the fresh air inlet the valve is closed. This is the sweating period. During this period, water which is in the center of the pasta is traveling to the surface, and the surface which had started to develop a crust in the pre-drying period begins to get soft. After this sweating period, a second drying starts, during which drying proceeds with the air being a little cooler and drier than the first time. As drying proceeds, the air is set cooler and drier, until drying is practically completed. The cycle is generally completed in about 24 hours (30).

b) <u>Continuous Drying</u>: Once the continuous extrusion press had shown that it was possible, the demand for a continuous drier became quite natural.

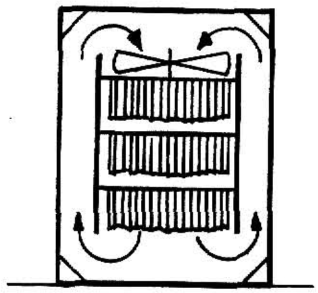

Figure 5. Diagram showing how the air is circulated vertically for long goods. (30)

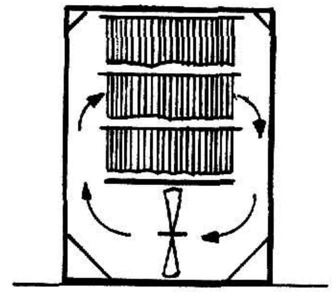

Figure 6. Diagram showing how the air is blown horizontally for long goods. (30)

By utilizing an oscillating conveyor as a shaker, which has proven to be a suitable feeding system, the short goods, coming from the pre-drier, are carried to the final drier. After the first final drying, the products proceed to the second final drier, and so on, until the product is dry. Always, critical temperatures and air humidities are taken care of in each of the drying steps (see Fig. 7 for a continuous flow).

Drying long goods is more difficult because it requires special handling and longer time to dry than short goods. The long goods have to be spread on the sticks, which are deposited on the drier and handled in through all the drying compartments. Each compartment has its own permanent drying condition (see Fig. 7 for a continuous flow of long goods). The sticks loaded with long goods are carried over a cutter, which cuts them to the exact length required. The trimmings fall on to a conveyor and are carried to a shredder and then returned to the mixer of the press (30).

A drying diagram should be as reliable as possible and have a built-in stability. Such a diagram, according to Hummel (30), would work along the following lines:

- An efficient pre-drier, using a wet bulb depression of about 4°C, in which the pasta would stay 2-3 hours, should be used. The water content

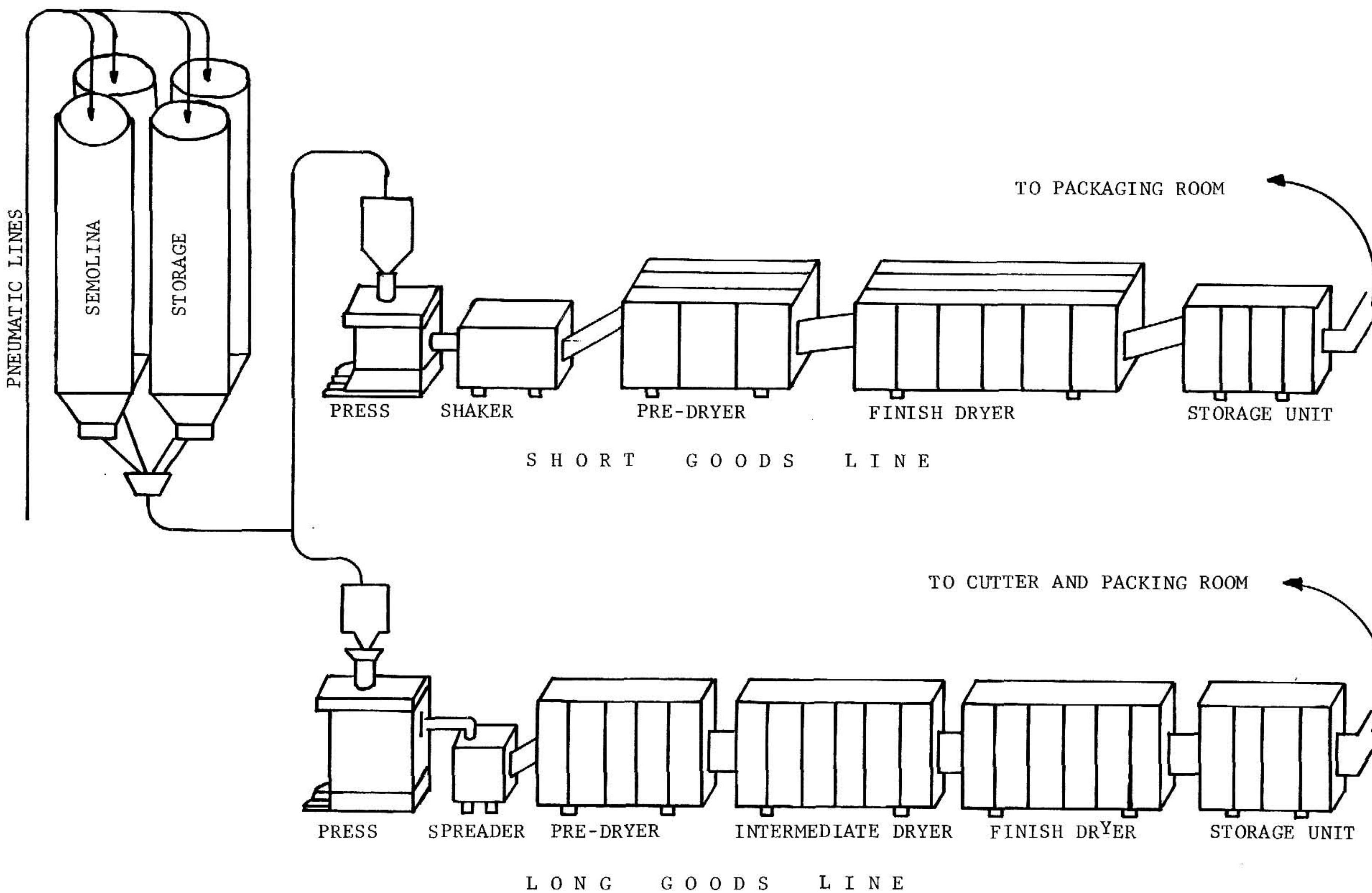

Figure 7. Material Flow in the Processing of Pasta Products. (24)

(on "as is" basis) should be brought down to near 20%. Up to this point, the warm macaroni products are soft and any stress is relieved by plastic deformation.

- A rest period or sweating period of at least one hour, at wet bulb depression of less than 1°C, and fairly high temperature (up to 50°C) should follow pre-drying. During this period, drying will stop. There may be a very small water absorption from the air. Water inside the product will distribute evenly. At the end of the sweating period, water and temperature should be evenly distributed within the product and there should not be built-in stresses as the product is still sufficiently plastic for all stresses to have been relieved. Drying may now be resumed.

- The drying should be such that the water gradient is low, so that the differences in the water content between the core of the product and the surface do not exceed 1%. This will be achieved by using a wet bulb depression of about 3°C and drying down to about 14.5% (on "as is" basis) in about 4 hours. After this, to activate drying, the wet bulb depression will be set to 5°C and drying will be finished in about six hours. The temperature should be set at 45-50°C. Hummel (30) considers that the main part of drying is the sweating period. It should be long enough to be sure that the water has had time to distribute evenly before drying is resumed. In general, Hummel (30) considers that for a successful drying, the following points should be kept in mind:

1. Pasta products are not a homogeneous material of standard composition and strength.
2. The passage from the plastic to the elastic state is gradual and depends on water content and temperature.

3. High temperatures help migration of water from the interior to the surface and they make a better color. Therefore, it is an advantage to choose temperatures as high as possible without spoiling the product.

Recent studies made by Manser (44), have found that drying temperatures in the range of 60 to 90^{o}C for dry bulb temperature are beneficial to the pasta quality and color. In addition, there are benefits in the reduction of total bacteria count, elimination of most pathogenic bacterias in pasta, and reducing the drying time.

c) Checking of Pasta: The most common defects of pasta products due to faulty drying are described by Hummel (30) and Hoskins (31) as follows:

1. Checking in the Pre-Drier: In the preliminary drier, when the pasta products are still soft, if drying proceeds too quickly, the surface will dry rapidly and case-harden, the interior will remain soft and plastic as the water cannot diffuse to the surface as quickly as it is evaporated. At a later period, diffusion will catch up with evaporation, the interior now shrinks more than the already case-hardened surface. This will pull the interior away from the surface.

Small holes will appear, like bubbles. These will not disappear even with most careful drying in the final drier. This defect is known as preliminary drier "checks". Preliminary checks will not spread over the whole product, as is the case with other types of checking, and also, it will not cause trouble during cooking. This checking is a signal showing that the setting of the preliminary drier is not correct. The air is too hot and too dry; therefore, it can be eliminated by reducing the wet bulb depression of air circulating the pre-drier.

2. Checking in the Final Drier: If the wet bulb depression is too high, the water on the surface of the macaroni products will evaporate faster than the water from the interior; and water from the interior will not be able to flow to the surface. The surface gets drier than the interior and a moisture gradient will develop which, as the product is already too hard for plastic deformation to occur, is going to set up stresses. The interior, which has a higher water content, will shrink more than the crust as drying proceeds, and it will be pulled away from the crust. This sets up stress when it is greater than the breaking strength of the pasta product and will show checking under the surface cracks. The checking makes the pasta product unfit for sale, their appearance is bad, and they fall to pieces when cooked. It has been tested by Hummel (30) that if the difference in water content of the interior to the exterior is more than 1.5%, the stresses involved will cause the pasta product to check.

3. Checking after Drier: If the moisture gradient develops before the pasta products have had time to harden, the difference in water content will lead to plastic deformation and no stresses. If during the further drying the moisture gradient is maintained, the products will leave the drier with no stresses, but with a built-in moisture gradient. The usual moisture test shows the mean water content and cannot detect this moisture gradient. The product will leave the drier with the required water content, they will look good and strong. Unfortunately, after a day or two, they will start to check and checking will spread all over. According to Hummel (20) and Hoskins (31), this is the worst kind of checking. The explanation of this type of checking is explained by Hummel (30), in that the water is diffused from the interior to the exterior. The interior continues to contract, the exterior, now taking up water from the interior,

that no longer evaporated, expanded. These differences in contraction and expansion set up stresses. As these attained the breaking strength the goods cracked. Often, the stresses induced by water gradient will not overcome the strength of the goods. The stresses will remain latent and only show up under certain conditions. For example, if the product is brought into air, the equilibrium water content is higher. In this case, the surface will absorb water first and expand more than the interior. This will generate extra stresses, which, together with the latent stresses, may be stronger than the breaking strength and cause the goods to crack. This may happen, for instance, if the product is brought from a warm chamber to a cool place. The layer next to the product surface will cool first. This will set the water traveling from the warm interior to the cooler exterior. The surface of the cooled product will absorb water and this may induce stresses that will check the product.

4. Tension Checks: These may occur when pasta products are brought into air with too high a wet bulb depression, so that the equilibrium water content is substantially lower than the actual water content. This will cause the surface to dry and shrink. The interior will not dry in the same proportion. Thus, fine cracks will appear on the surface. Usually, these cracks stay at the surface, and like the bubbles in the pre-drier, seldom cause trouble cooking (31, 30).

Color Additives, Its Petitions and Certification

The current legislation pertinent to the regulation and use of color additives in the U.S. is the Food, Drug and Cosmetic Act of 1938 as amended by the Color Additives Amendments of 1960. To understand the present color additive situation and to judge the future, it is necessary to have the past history of color additives.

According to Noonan (57), in the 1900's, some light dyes were being used in the U.S. for coloring food. At that time there were no regulations regarding the nature and purity of these dyes, and the same batch of color used to dye cloth might find its way into candy.

The first comprehensive legislation was the "Food and Drug Act of 1906" which listed seven dyes which were permitted for use in foods. The seven original permitted colors were as follows: Amaranth, Erythrosine, Indigotine, Light Green, Naphthol Yellow, Orange 1 and Ponceau 3 R.

A system was set up for the certification of batches of these colors by the Department of Agriculture. At that time certification was not mandatory; however, color manufacturers soon found it advantageous to obtain certification.

The original list of colors left much to be desired to fulfill all the needs of the food industry and through the years additional colors were added, but only after physiological testing. In 1916 the color additive Tartrazine was added to the list.

The Food, Drug and Comestic Act of 1938 superseded the Act of 1906 and broadened the scope of Certified Colors, creating three categories: FD&C Colors, D&C Colors and External D&C Colors.

Following the passage of the Food, Drug and Cosmetic Act of 1938, the situation was peaceful until the early 1950's; unfavorable incidents occurred as a result of overuse of color in candy and on popcorn. The colors involved were FD&C Orange No. 1 and FD&C Red No. 32. This incident,coupled with chronic toxicity in animal-feeding studies, led to the banning of FD&C Orange No. 1, Orange No. 2 and FD&C Red No. 32.

After several opinions in the courts, the Supreme Court banned all colors even though the FDA admitted they were not endangering the public health. Under the sponsorship of the Certified Color Industry and the FDA, the Color Additives Amendments became law on July 12, 1960. The law consisted of two Titles. Title I is the so-called permanent part; Title II, the temporary part (5).

Title I sets up uniform rules for all permitted colors, both certified and uncertified. The term "color additive" is used to describe "any dye, pigment or other substance capable of coloring a food, drug or cosmetic on any part of the human body." The Secretary of Health, Education and Welfare is given the authority to decide whether a color additive should be classed as certified or uncertified. The law allows the Secretary to list color additives for specific uses and also to set conditions and tolerances (limitations) on the use of color additives.

Title I also includes the Delaney cancer clause which states that a color additive cannot be listed for any use whatever if it is found to induce a cancer when ingested by man or animal.

Title II, the so-called temporary law, is designed to permit use of current color additives pending the completion of scientific investigations needed to determine the suitability of these materials for permanent listing. The original closing date for the provisional listing of the color additives was two and a half years after the date of passage of the law. However, the Secretary of Health, Education and Welfare has the power to grant extensions of the closing dates, which he has done many times. In retrospect, the Color Additives Amendments have been salutary; however, difficulties have arisen in obtaining permanent listing of the certified color additives.

Starting in February 1965 with FD&C Yellow No. 5, petitions for permanent listing were submitted to the Food and Drug Administration, and by

1968 all petitions had been submitted. Because of a dispute (and subsequent court case) over interpretation of the color regulations regarding pre-marketing clearance for cosmetics between FDA and the Toilet Goods Association, no action was taken on the petitions. However, in July of 1969, FD&C Yellow No. 5 and other colors were permanently listed for use in foods and ingested drugs with limitations only for good manufacturing practice. Pending settlement of the cosmetic issue, provisional listing was maintained for topical drug and cosmetic uses of these colors.

In the September 11, 1971, issue of the "Federal Register", the FDA also stated that for provisional listing beyond December 31, 1971, the ingested certified colors (nine FD&C and sixteen D&C colors) should have teratology and multigeneration reproduction studies in progress by December 31, 1971.

Since all of the FD&C colors are undergoing additional testing, the difference between provisional and permanent listing is academic (57).

At present, there have been unforeseen and unavoidable delays in conducting the testing, FDA said in a statement on the new deadlines, which range from May 30, 1981 to September 30, 1983 (6). There are still twenty-three colors now provisionally listed and all have been in use since before 1960. According to the agency, the deadline extensions are needed because of several factors: more time is needed to study the plans for some of the safety studies, while other studies were started before there was FDA approval of the design of the testing. Also, there is a shortage of adequate animal testing laboratories and trained pathologists to do the testing. These shortages have resulted in a "backlog" in animal testing that is "nationwide", according to FDA.

FDA believes that all twenty-three colors can be used safely while the testing goes on.

MATERIALS AND METHODS

This study was conducted in two sections to determine: a) the suitability of Hard Red Winter wheat for making spaghetti and the effect of particle size in its quality, and b) the incorporation of a dye or coloring additive in Hard Red Winter wheat made spaghetti for matching the yellow color of durum wheat made spaghetti.

Materials

During the initial stage, the following materials of wheat granulars were obtained:

a) Commercial durum wheat semolina from Peavy Company, Hasting, Minnesota.

b) Commercial Hard Red Winter farina (-20w +40w) and (-40w +60w) from Whitewater Mill Inc., Whitewater, Kansas.

Preparation of Materials

For the experiment, we were interested in having three different granulations of Hard Red Winter wheat. Also, we were interested that the materials for testing the effect of particle size in spaghetti quality all came from the same sample, and that the only difference was the particle size. We did not want any change in protein and ash.

One-half of the sample (150 lb) of farina (-20w +40w) was ground to flour through the flow in Fig. 8 until all of the product passed through a 9XX bolting cloth. Then the flours were remixed in a Wenger horizontal mixer for 20 minutes.

When all the materials were ready, they were placed individually in polyethylene bags in a fiber drum and stored in the cold room until needed.

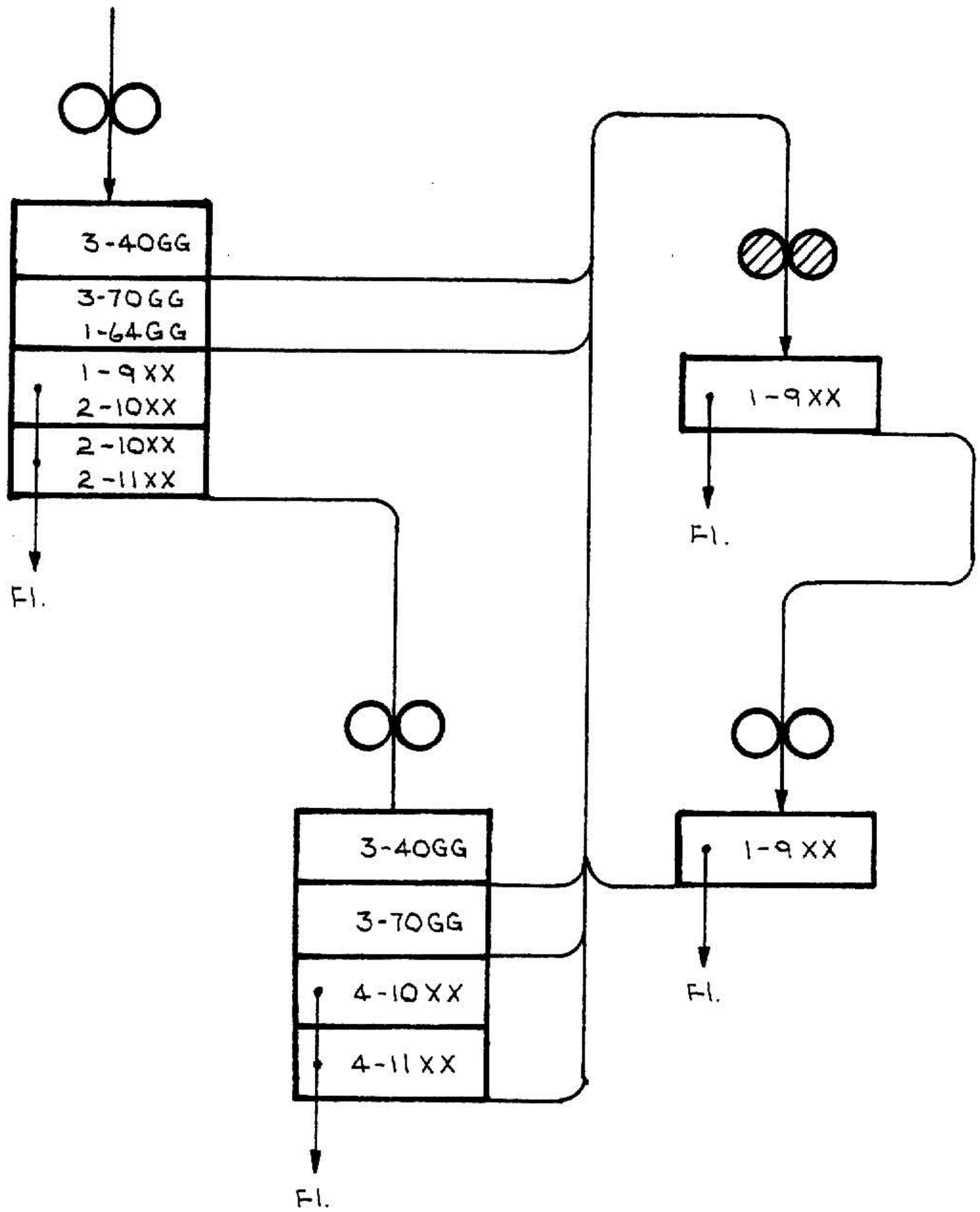

Figure 8. Flow for Grinding Farina (-20W +40W) to Flour.

Characteristics of the Materials

Particle Size: The particle size distribution of the materials was determined using a RO-TAP testing shaker (The W. S. Tyler Co., Cleveland, Ohio) equipped with U.S. Standard sieves #20, 40, 60, 80, and 100. A 100 g sample was sifted for three minutes. The percent of each fraction was calculated by weighing the overs of each sieve and the thrus of the U.S. 100 sieve.

Moisture Content: The moisture content of the materials was determined by the Air-Oven Method, one-stage (AACC Method 44-15A). The method requires the heating of a 10 g sample at 130°C for 1 hour. One hundred minus the percent remaining after heating is the moisture %.

Protein Content: The protein content of the materials was determined by the Crude Protein-Improved Kjeldahl Method (AACC Method 46-10). The total nitrogen content is multiplied by 5.7 and the results are expressed as percent protein on a 14% moisture basis.

Ash Content: The ash content of the materials was determined by the Ash-Basic Method (AACC Method 8-01). The percent remaining after ignition is expressed as percent ash on a 14% moisture basis.

Wet Gluten: 10 g of flour and 5.2 ml of 2% salt (NaCl) solution were placed in the Glutomatic test chamber and mixed for 20 sec. The gluten is then washed for 5 min. and separation in gluten and soluble starch products is obtained. The gluten ball is then divided and placed in a centrifuge for 1 min. to remove excess water. The weight of the centrifuged gluten x 10 is equal to "Percent Wet Gluten."

Dry Gluten: The gluten from the wet gluten process above is placed between two teflon-coated heated plates for approximately 4 min. The weight of the dry gluten x 10 is equal to Percent Dry Gluten."

Spaghetti Processing

Mixing and Extrusion: Spaghetti was prepared in the DEMACO (DeFrancisci Machine Corporation) 25 lb/h laboratory press. This machine is equipped with a mixer which is fed through a rotary airlock with the help of a volumetric feeder of the vibrator type (Fig. 9). In conjunction with the volumetric feeder, the water feed is taken care of with a water-flow meter for adjusting the correct proportion of water to farina, semolina or flour. A percentage timer turns the flour feed and water on and off for adjusting the percentages of each minute in order to control the total rate of flow per hour.

The mixer (Fig. 10) is of the twin shaft mixer type with blades that wipe down the sides of the mixer and up in the center. The mixer was maintained under 20 inches of H_2O vacuum in order to eliminate bubbles of air.

The auger (Fig. 11) is made of stainless steel with bronze tipped flight crests to give a good bearing surface against the hardened steel barrel surface or cylinder. The barrel surface has longitudinal grooves to keep the dough from turning as the auger turns. After the auger, the dough passes through a sheet metal plate perforated by small holes of approximately 5/64 inches and held by a stainless steel disk with holes of approximately 12/64 inches, called the kneading plate (Fig. 12). The sheet metal plate is for straining out any pieces of hard dough or extraneous matter that can plug the extrusion die. The kneading plate is used for assuring a well mixed mass of uniform characteristics. The mass then is ready to be passed thru a brass die. This is accomplished by passing the dough through the extrusion head which connects and holds the extrusion die. The die is a D. Maldari and Sons Inc., Brooklyn, N.Y., number 38927 with 84 holes of 5/64 inches each (Fig. 13). A schematic drawing of the extrusion process can be seen in Fig. 14. After the die, the strands of pasta were placed on a rod, cut to 16" lengths and placed into the drier.

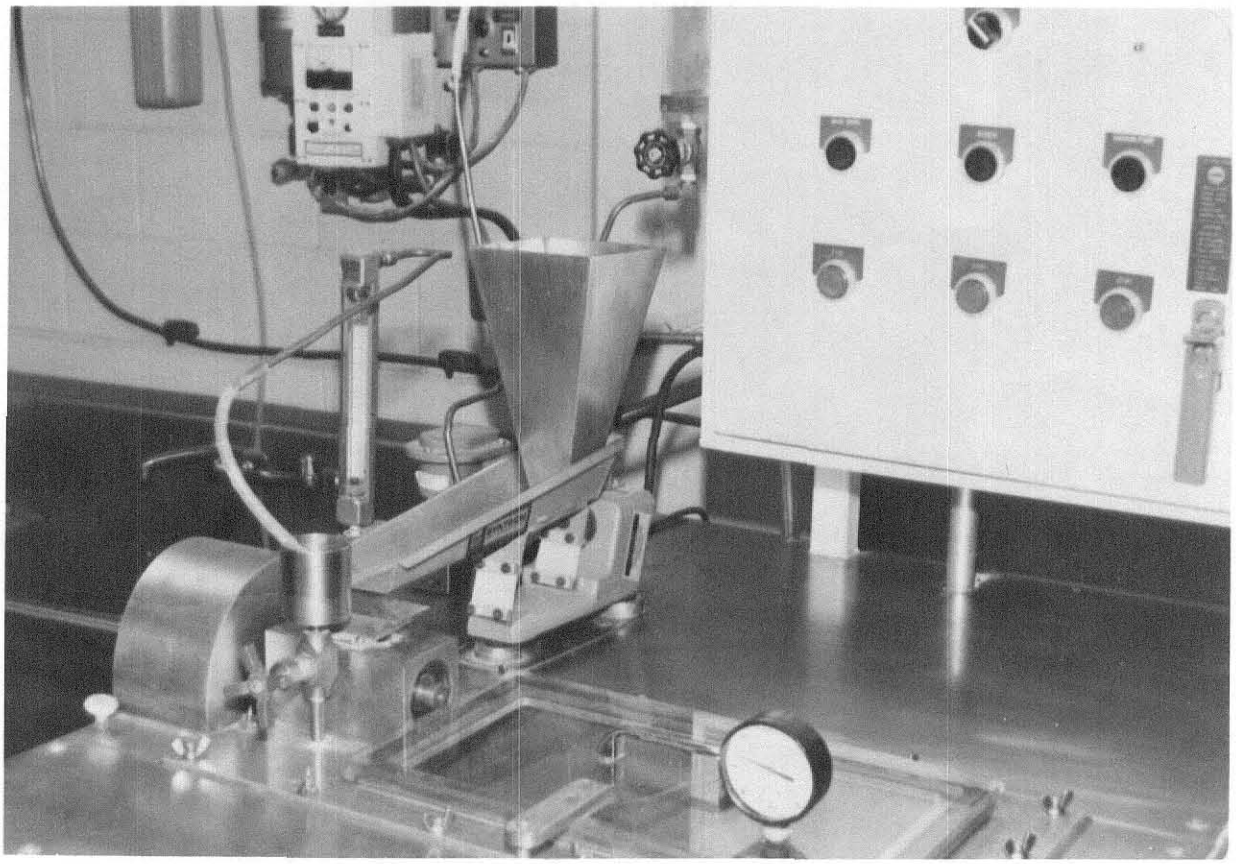

Figure 9. Rotary Airlock and Volumetric Vibrator Feeder.

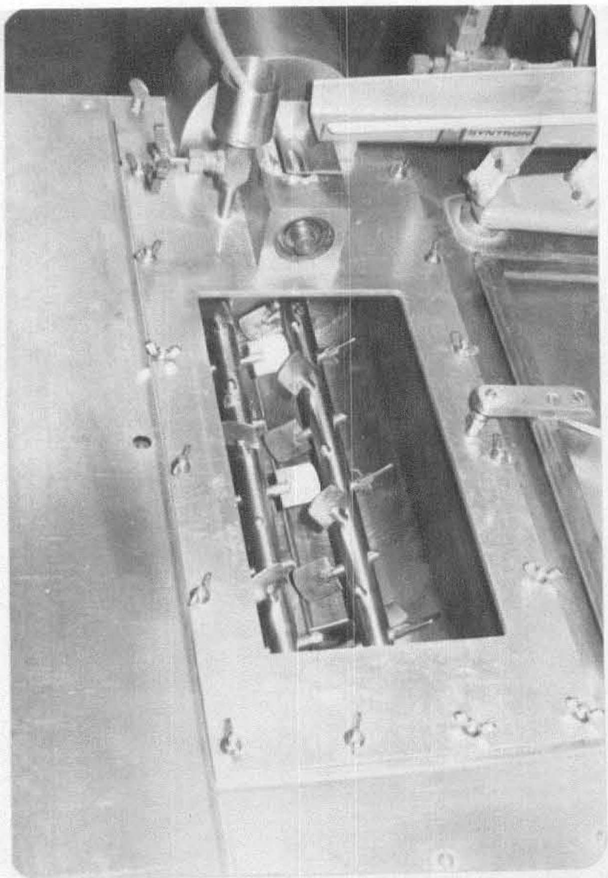

Figure 10. Twin Shaft Mixer

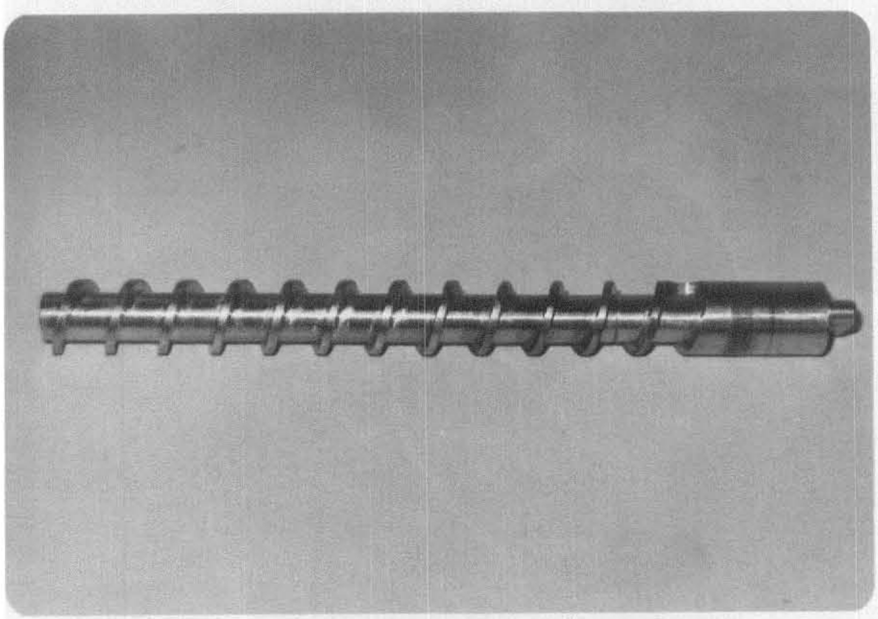

Figure 11. Extrusion Auger.

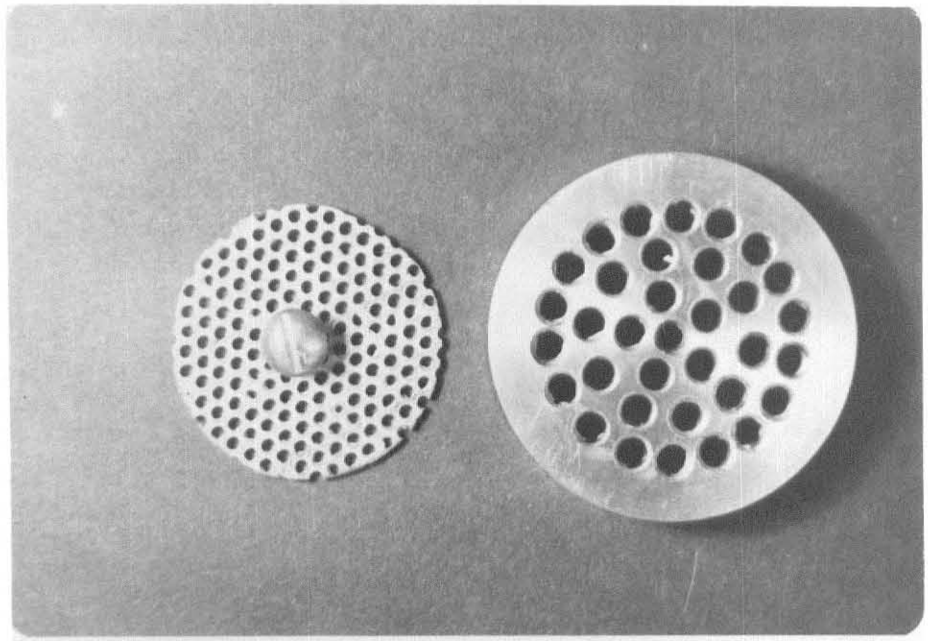

Figure 12. Kneading Plate.

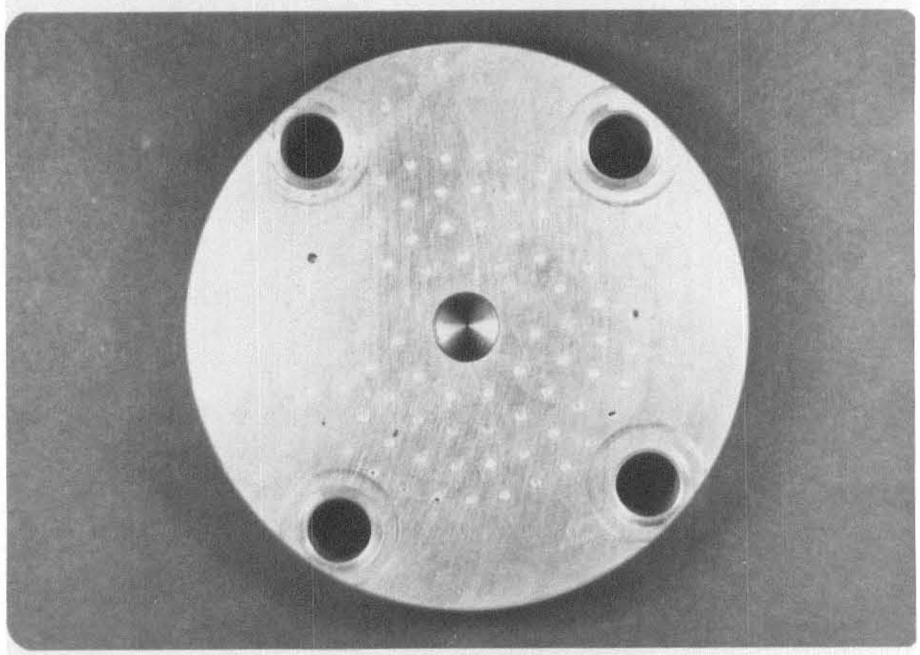

Figure 13. Extrusion Die.

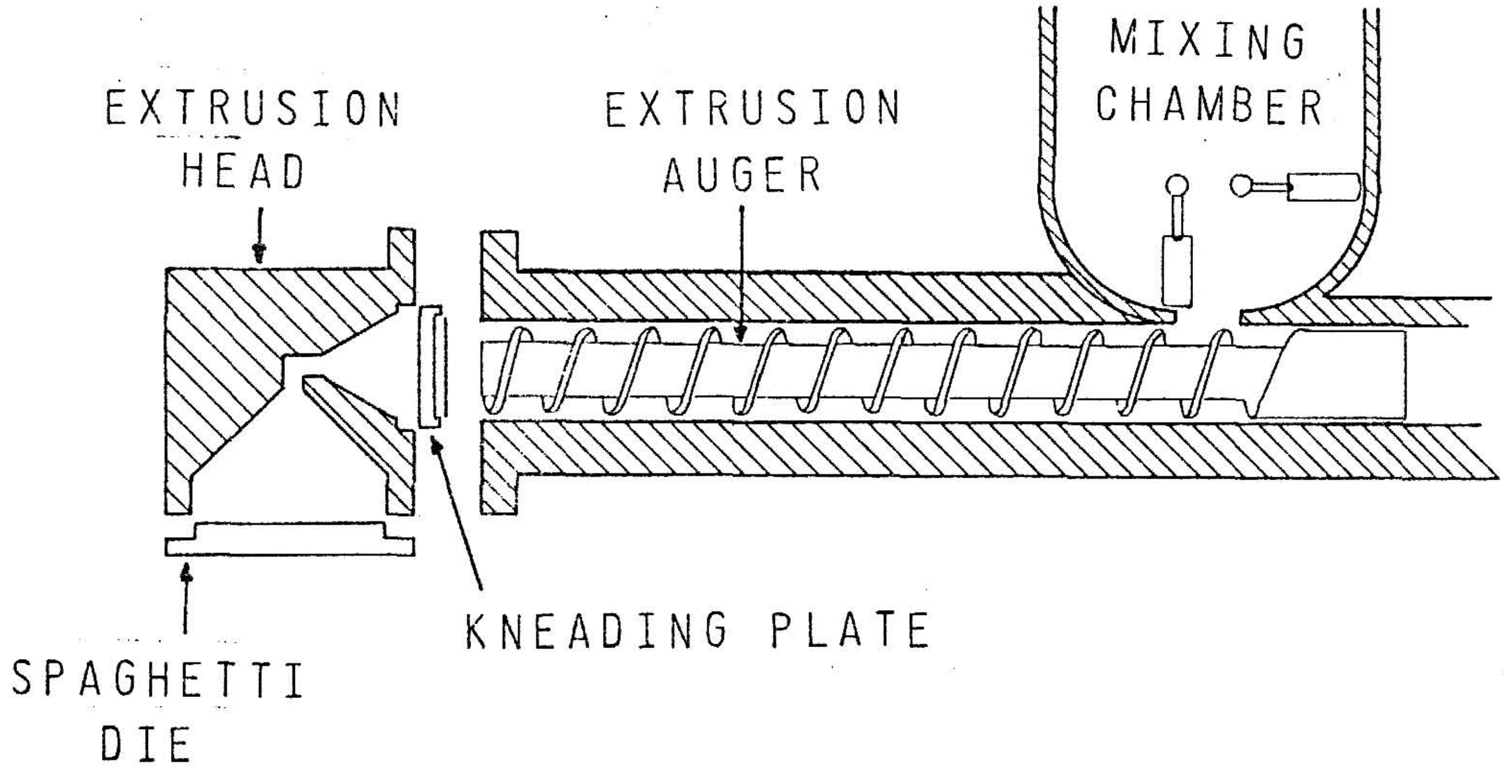

Figure 14. Schematic Representation of Demaco Laboratory Continious Extrusion Press.

For the experimental work, the samples were not mixed at the beginning in the press mixer. Samples of 1.5 kilograms (1,500 g) were placed in a Hobart A-200 mixer (Fig 15). Water at a temperature of 50°C was added to the product in the first two minutes at speed 1. After all the water had been added (two minutes), the mixer was stopped. The paddle was cleaned if there was any product sticking and the mixing continued at speed 1 for one minute. Then the speed of the mixer was switched to speed 2 and the mixing continued for two more minutes, for a grand total of five minutes for all the mixing process in the Hobart A-200. The dough was then transferred to a polyethylene bag for a 20 minute resting period. The rested dough was placed in the vacuum mixer and mixed for one minute. Then the extrusion screw or auger and the vacuum pump were turned on and the extrusion proceeded as above. The water around the mixer and barrel were held at 50°C and the speed of the screw at 25 RPM.

Drying: The spaghetti strands were placed on stainless steel rods in the drying cabinet. The drying operation was done with a predrying and final drying with three stages. The temperature was held constant at 42°C, while the relative humidity changed as follows:

Pre-drying :	relative humidity (R.H.) of 75% for 1 hour.
Final-drying:	the first stage or "sweating period" held the product at 95% R.H. for 1 hour; the second stage exposed the product to 78% R.H. for 8 hours, and the third stage maintained the product to 65% R.H. for 10 to 12 hours.

The changes of relative humidity between first and second stage, and second and third stage took approximately one and a half hours (1½ hours).

At the end of the drying operation the heat was shut off and samples were cooled in the drier.

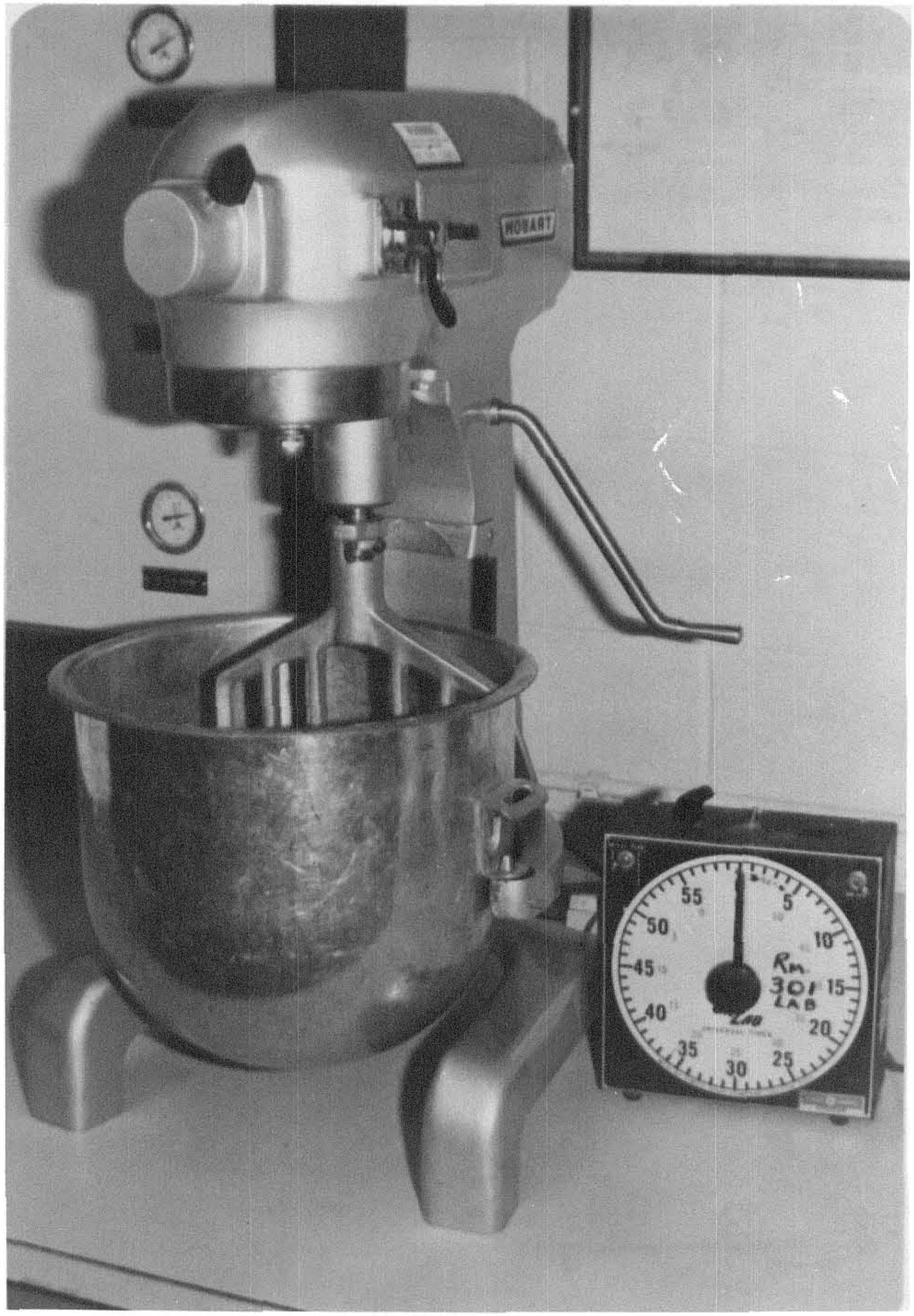

Figure 15. Hobart A-200 Mixer.

Spaghetti Testing Procedures

The evaluation of the spaghetti was done modifying the AACC method 16-50 (Cooking Characteristics of Macaroni). The firmness, water absorption during cooking and resistance to disintegration were tested as shown by the schematic procedure in Fig. 16.

A 600 ml tall form, lipless beaker with 200 ml of distilled boiling water, 10 g of spaghetti strands, which had been broken into approximately 2" lengths and a watch glass cover were placed in a mineral oil bath (Fig. 17) at 107°C (± 1°C). The spaghetti was cooked for 5, 10, 15, 20, 25 and 30 minutes with brief stirrings at five minute intervals (stir 10 times clockwise). Then the beaker was removed from the oil bath, the spaghetti was drained in a strainer, and the spaghetti and beaker were washed with distilled water. After draining for five minutes, the spaghetti was transferred to a tared beaker and weighed. The spaghetti was then stored under water for five minutes before firmness measurements were taken with the instrument shown in Fig. 18.

The water in which spaghetti was cooked and the washing water were placed in a tared beaker for evaporation of the water in an oven at 130°C for eight hours.

For measuring of firmness, selected samples at random from the cooked spaghetti were located in the firmness tester (Fig. 19) and a load at a constant rate was applied until the strand was cut more than its diameter. Five of these such tenderness tests were made.

The water absorption was determined by the increase in weight of the spaghetti upon cooking and expressed as a %.

The firmness was evaluated by reading the maximum weight in grams to shear one strand of cooked spaghetti (the peak of the curve from the recorder).

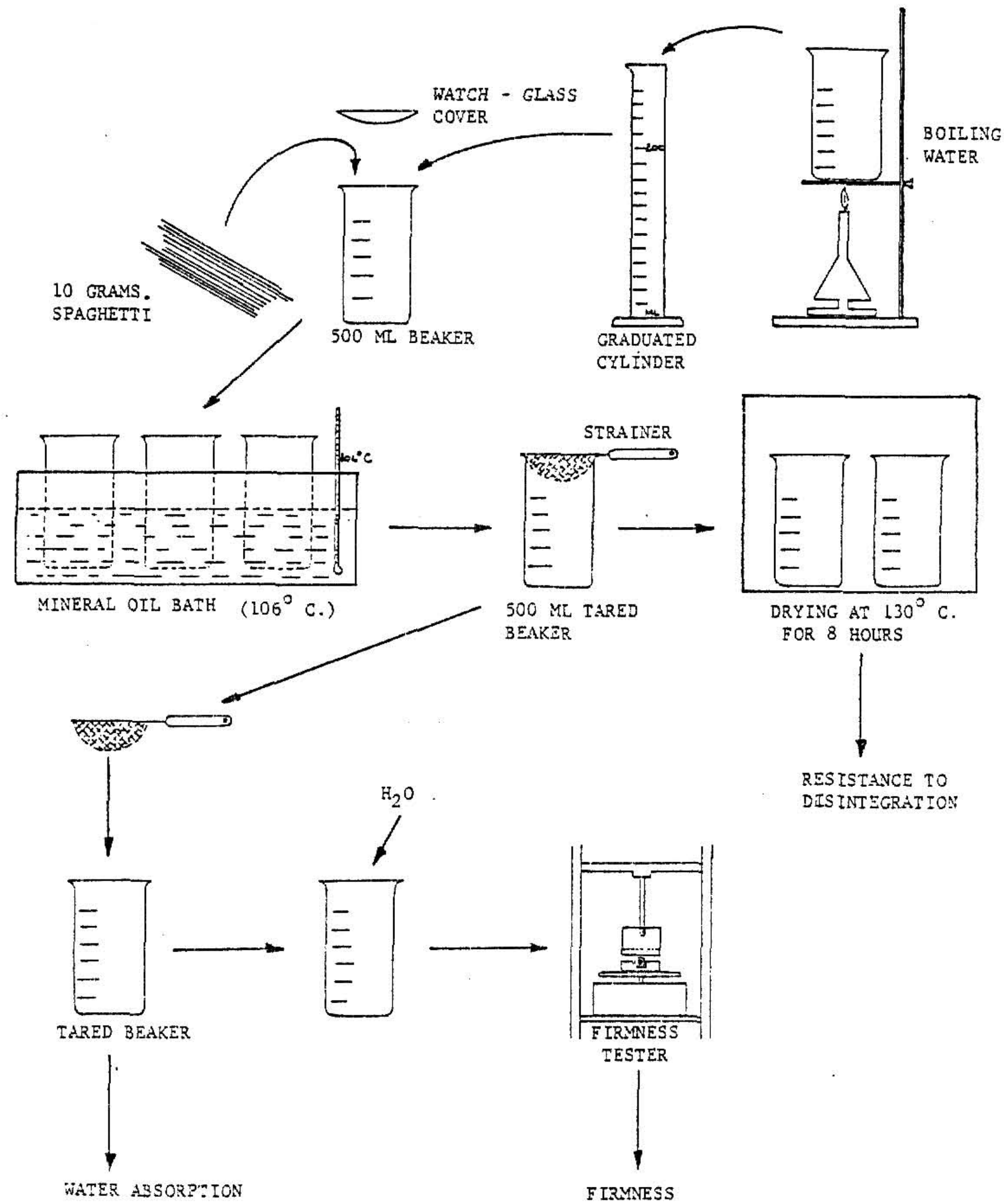

Figure 16. Schematic Representation of Spaghetti Testing Procedure.

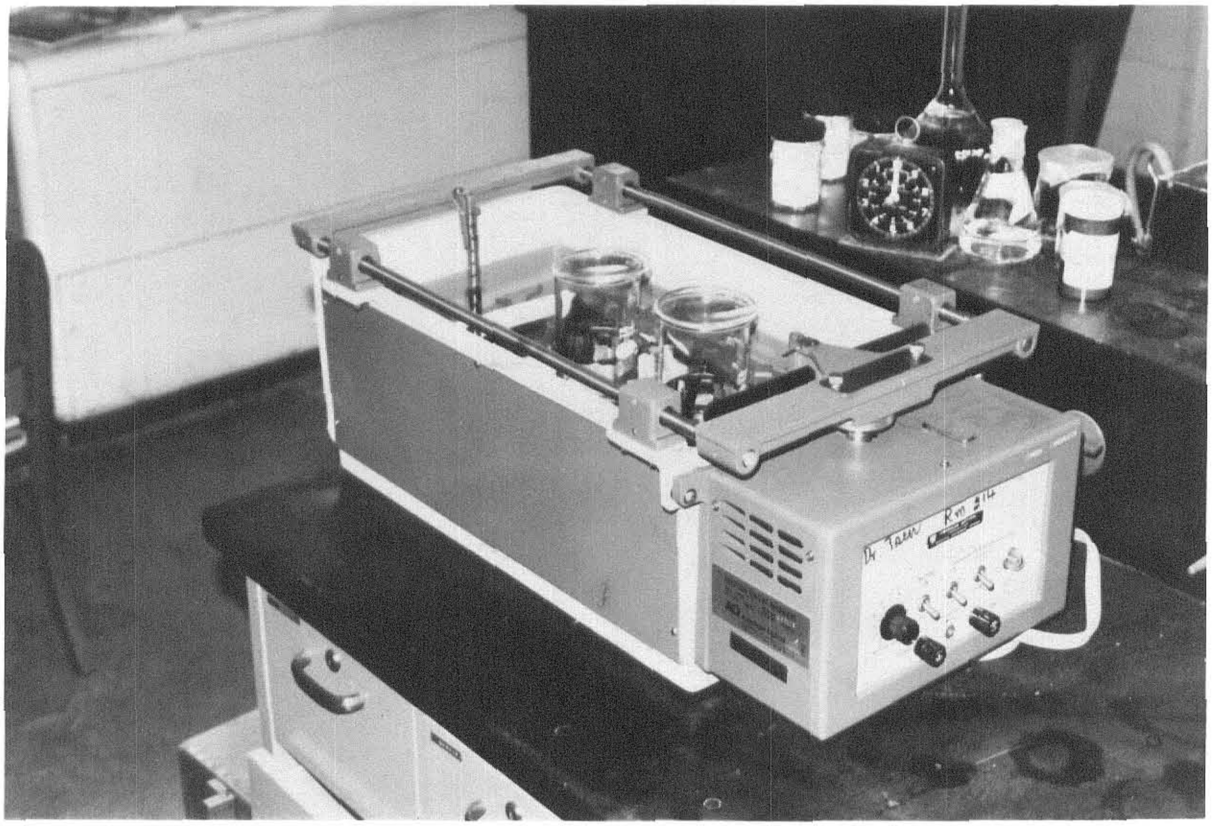

Figure 17. Mineral Oil Bath.

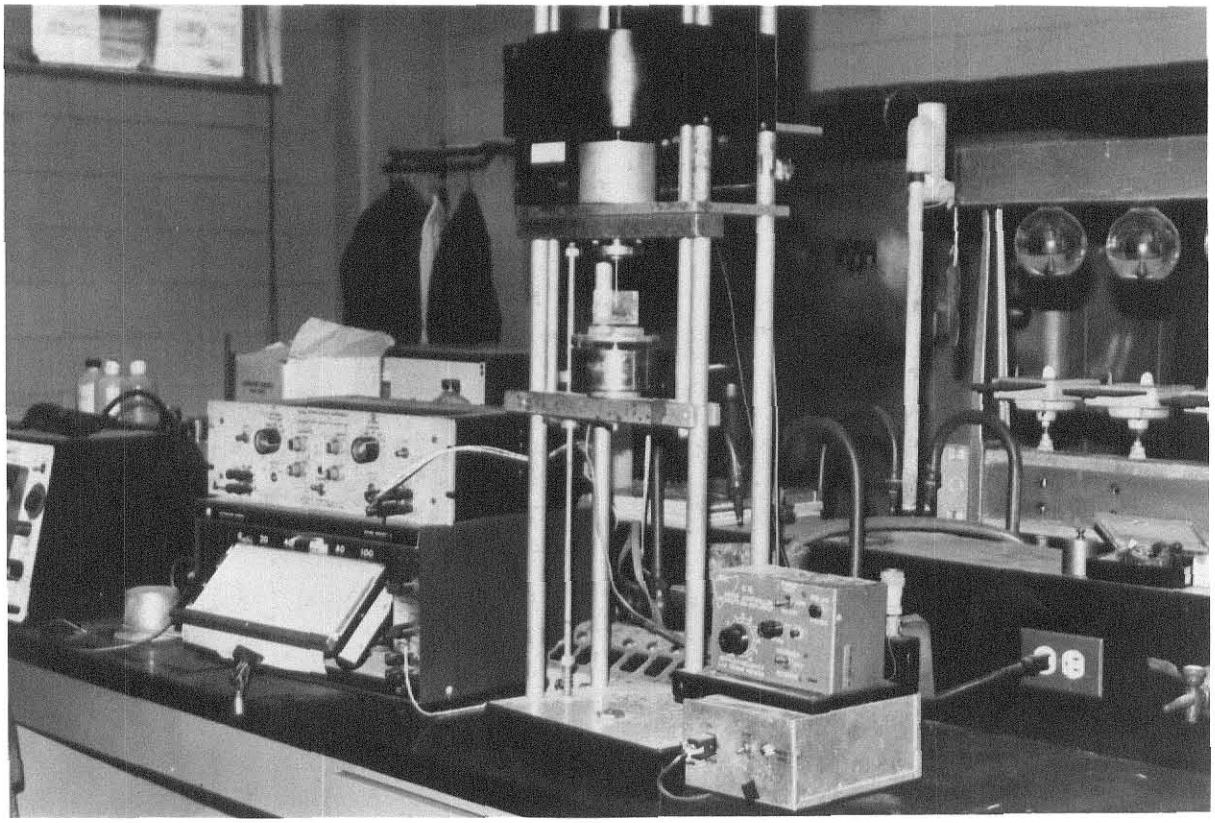

Figure 18. Firmness Tester.

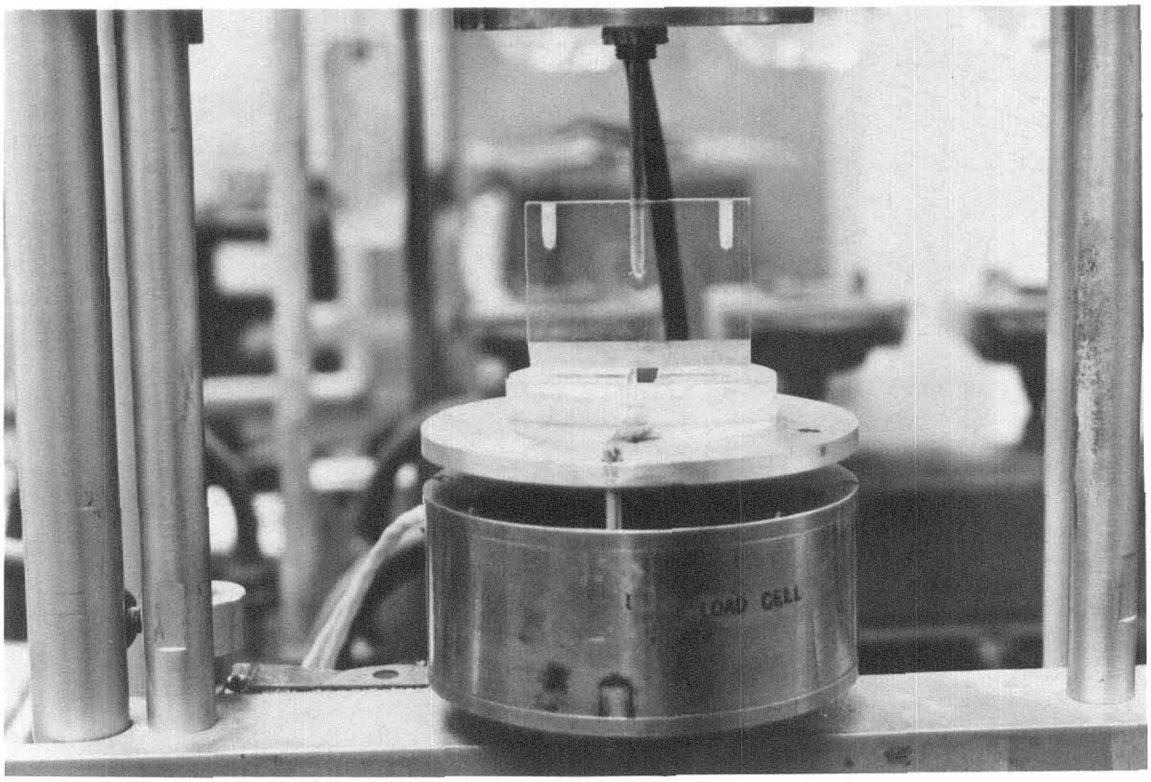

Figure 19. Close View of the Load Cell and Plastic Tooth.

The resistance to disintegration or cooking loss was obtained by the increase in weight of the beaker before and after water evaporation and expressed as a water soluble %.

Incorporation of coloring Additive or Dye in Pasta

The coloring additive FD&C yellow No. 5, common name Tartrazine, was used for matching the natural yellow color of durum wheat spaghetti when Hard Red Winter raw materials were used for making spaghetti.

A solution of 1 gram of yellow No. 5 in 75 C.C. of water was made. Then pipet amounts of ½ C.C., 1 C.C. and 1½ C. C. of that solution were added to the total water required to make the dough prior to the incorporation in the Hobart A-200 mixer.

Data Analysis

The results were evaluated using analysis of variance techniques (64). The model employed considers product (P), absorption (A) and time (T) as main effects, and included estimates of all two factor interactions (P x A, P X T and A x T). Since no duplicate observations were available, the three factor interaction (P x A x T) with 45 degrees of freedom was used as the error for testing effects. The time effect was further investigated by breaking down the available degrees of freedom into linear, quadratic and cubic components; in this breakdown A x T and P X T significant interaction of time with other factors were also considered. Furthermore, comparisons among categories included in the main effects were made taking into account all the significant interactions detected in the primary analysis and using Duncan's multiple range test (64).

This model was used in the evaluation of every parameter considered in the study: disintegration, firmness and water absorption during cooking.

The results are presented separately for each of the parameters under consideration.

RESULTS AND DISCUSSION

Particle Size Distribution

Table II shows the particle size distribution for the raw materials. The commercial HRW farina (-20w +40w) was the coarser particle size and the flour from HRW farina (-20w +40w) was the thinner particle size. The particle size of commercial HRW farina (-40w ±60w) and commercial durum semolina were intermediate granulations and very similar between them.

Chemical Characteristics

The chemical characteristics for the raw materials are shown in Table III. In general, the ash content was higher for the commercial durum semolina, while those of hard red winter farinas had the lowest ash content. The same observation can be made for the protein content but was not as pronounced.

Wet gluten and dry gluten percent were higher for the commercial durum semolina than for the commercial hard red winter farinas, which agrees with the results obtained for the protein content.

Evaluation of Spaghetti

Disintegration, water absorption and firmness of spaghetti during cooking were the three parameters that were used for testing the quality of spaghetti.

Spaghetti was prepared from each of the four raw materials and since there is no method for determining the best water absorption for extrusion of pastas, water absorptions of 27, 28.5, 30, and 31.5 percent were used for preparing the dough and testing each raw material.

TABLE II

Particle Size Distribution for the Raw Materials

U.S. Sieve No.	Sieve opening (microns)	Commercial HRW farina (-20W +40W)	Commercial HRW farina (-40W +60W)	HRW flour from farina (-20W +40W)	Commercial durum semolina
On 20	840	0.5	0	0	0
On 40	420	91	0.5	0	32
On 60	250	7	98	0	53
On 80	177	0.5	0.5	51	12.5
On 100	149	0.5	0.5	44	2
Through 100		0.5	0.5	5	0.5

100 Grams of product for three minutes in a RO-TAP sifter

TABLE III

Chemical Data for the Raw Materials

	Moisture (%)	Protein (%)	Ash (%)	Wet gluten %	Dry gluten %
Commercial HRW farina (-20w +40w)	13.2	10.6 (10.5*)	.39 (0.39*)	26.9	10.4
Commercial HRW farina (-40w +60w)	13.4	11.0 (10.9*)	.41 (0.41*)	28.1	10.8
HRW Flour from farina (-20w +40w)	12.6	10.7 (10.5*)	.40 (0.39*)	27.8	10.3
Commercial durum semolina	13.4	12.4 (12.3*)	.67 (0.67*)	35.2	11.9

*14% Moisture basis

Disintegration of Spaghetti During Cooking:

The disintegration during cooking data for the four products and four different absorptions is shown in Table IV. The mean over the products original absorption* and time presented in Table V, VI and VII helps in understanding the nature of the absorption x time, product x time and product x absorption interaction, respectively. The time trends in disintegration during cooking with cooking time are illustrated by original absorption in Fig. 20 through 23 and by products in Fig. 24 through 27.

The results of the primary analysis of variance for disintegration of spaghetti during cooking (data of Table IV) presented in Table VIII show that product, original absorption and cooking time have a significant effect on the disintegration of spaghetti during cooking, with only the product x absorption interaction showing significance. This analysis also reveals that the time effect on disintegration is primarily linear, and that the interaction of the linear effect of time with either absorption or product was not as significant as could be expected because of the non-significance of the interactions of the total time effect with either product or absorption.

The overall comparison among original absorptions without reference to either product or cooking time (Table VII) shows significant differences ($P \leq 0.05$) in disintegration during cooking with rankings in the same order as the original water absorption for the dough preparation in manufacturing the spaghetti. The decrease in percent of disintegration during cooking with increasing percent of original water absorption in preparing the spaghetti is not significant between A3 and A4, but it is significant between the other two absorptions. The trend is predominantly linear as can be seen in Fig.28.

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*% of water added in preparing the dough in the spaghetti preparation.

TABLE IV

Disintegration During Cooking (%)

Absorption %		5 Min	10 Min	15 Min	20 Min	25 Min	30 Min	$\bar{X}$
27	Commercial HRW farina (-20W +40W)	3.1	4.2	5.3	6.4	7.2	8.1	5.72
27	Commercial HRW farina (-40W +60W)	3.2	4.5	5.5	6.6	7.3	8.1	5.87
27	HRW Flour from farina (-20W +40W)	3.5	4.8	5.9	7.0	7.9	8.6	6.28
27	Commercial durum semolina	3.5	4.7	5.6	6.8	7.7	8.5	6.13
28.5	Commercial HRW farina (-20W +40W)	2.9	4.1	5.1	6.0	6.8	7.7	5.43
28.5	Commercial HRW farina (-40W +60W)	3.2	4.2	5.4	6.5	7.4	8.3	5.83
28.5	HRW Flour from farina (-20W +40W)	3.3	4.3	5.4	6.7	7.5	8.5	5.95
28.5	Commercial durum semolina	3.4	4.5	5.7	6.9	7.7	8.6	6.13
30	Commercial HRW farina (-20W +40W)	3.0	4.0	5.2	6.3	7.0	7.8	5.55
30	Commercial HRW farina (-40W +60W)	3.1	4.2	4.9	6.4	7.3	7.9	5.63
30	HRW Flour from farina (-20W +40W)	3.0	4.1	4.9	6.2	6.9	7.7	5.47
30	Commercial drum semolina	3.3	4.5	5.6	6.7	7.6	8.5	6.03
31.5	Commercial HRW farina (-20W +40W)	2.9	4.0	5.1	6.3	7.1	7.8	5.33
31.5	Commercial HRW farina (-40W +60W)	3.1	4.3	5.2	6.3	7.1	7.9	5.65
31.5	HRW Flour from farina (-20W +40W)	2.8	3.9	4.9	5.9	6.8	7.6	5.32
31.5	Commercial durum semolina	3.4	4.4	5.5	6.5	7.6	8.4	5.97

TABLE V

Disintegration During Cooking by Original Absorption and Cooking Time (A X T Interaction)

Absorption	Time (min) 5	10	15	20	25	30	$\bar{X}$	
27.0%	3.33	4.55	5.58	6.70	7.53	8.33	6.00	A
28.5	3.2	4.28	5.40	6.53	7.35	8.28	5.84	B
30.0	3.10	4.20	5.15	6.40	7.20	7.98	5.67	C
31.5	3.05	4.15	5.18	6.25	7.15	7.93	5.62	C

Means with the same letter are not significantly different

Alpha level = 0.05 DF = 45 MS error = 0.010713

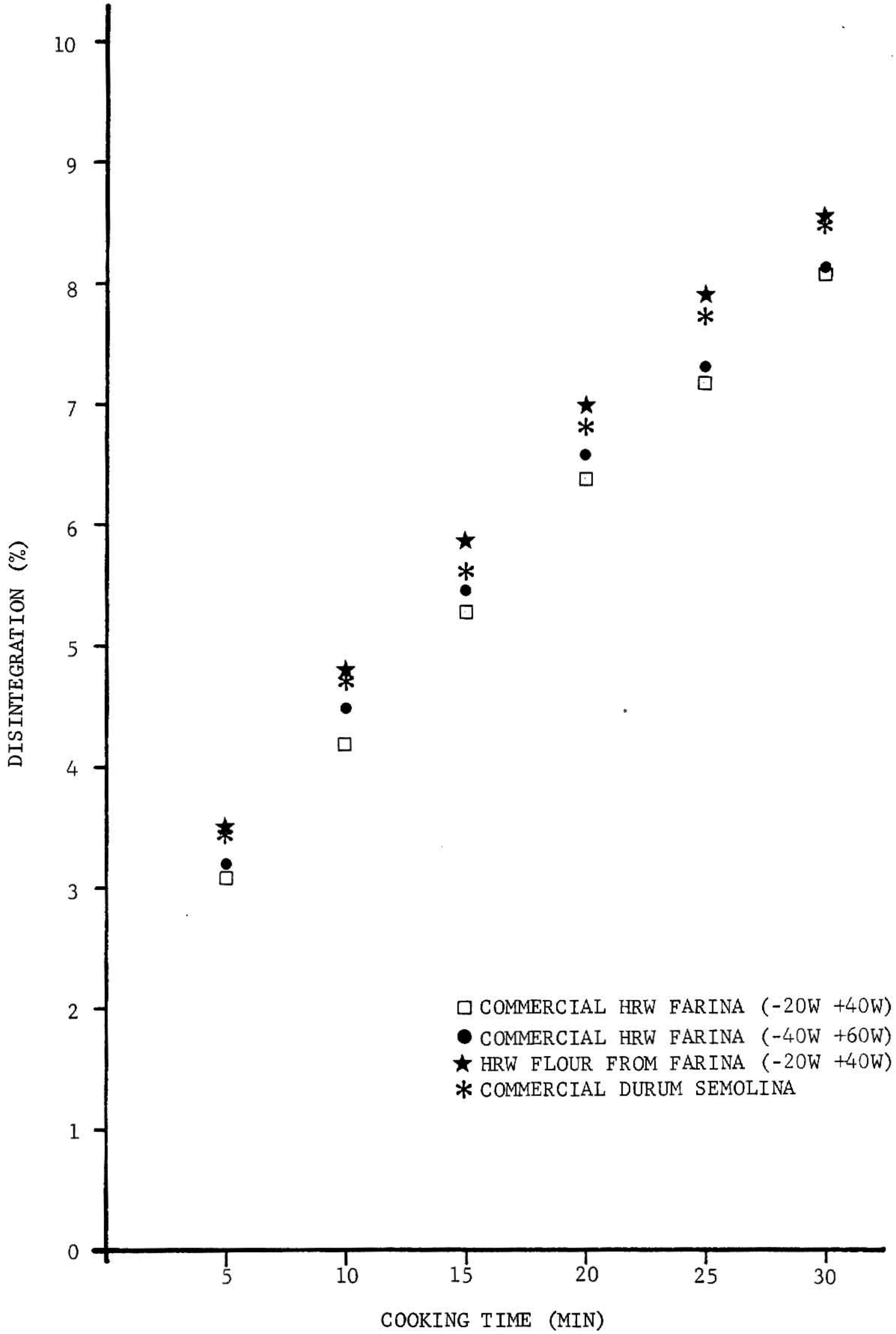

Figure 20. Disintegration During Cooking for 27% Original Water Absorption Spaghetti .

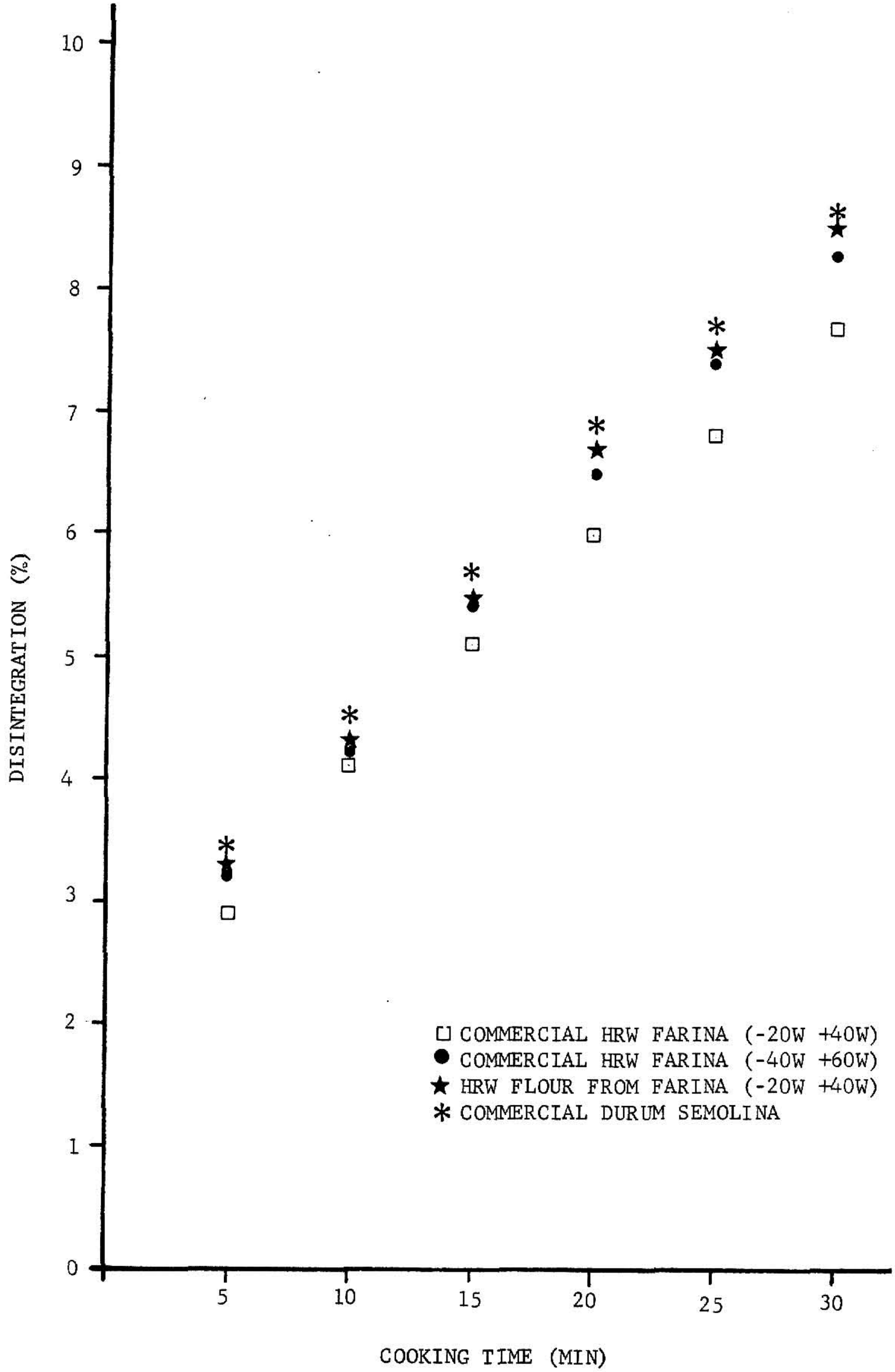

Figure 21. Disintegration During Cooking for 28.5% Original Water Absorption Spaghetti .

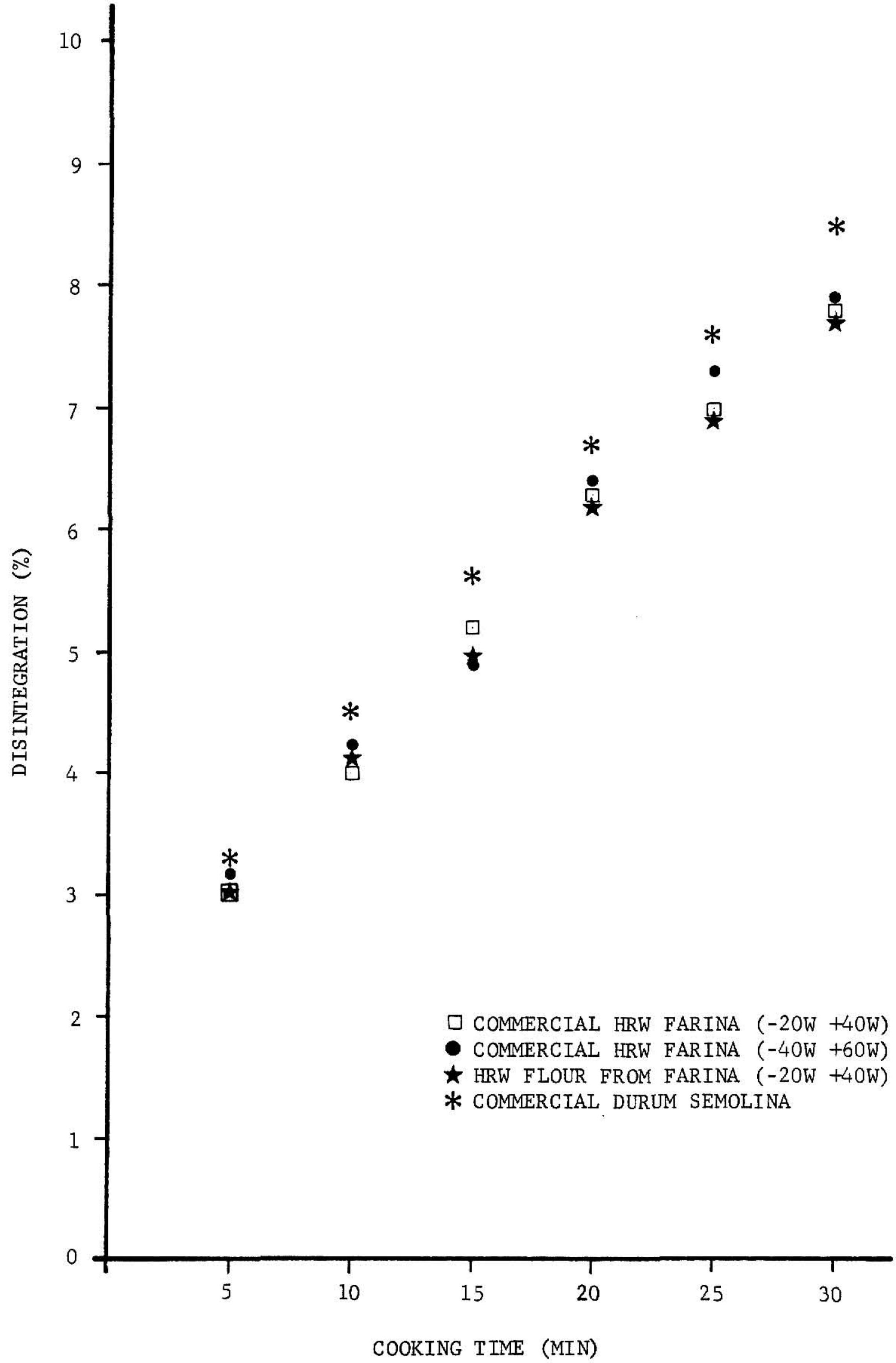

Figure 22. Disintegration During Cooking for 30% Original Water Absorption Spaghetti .

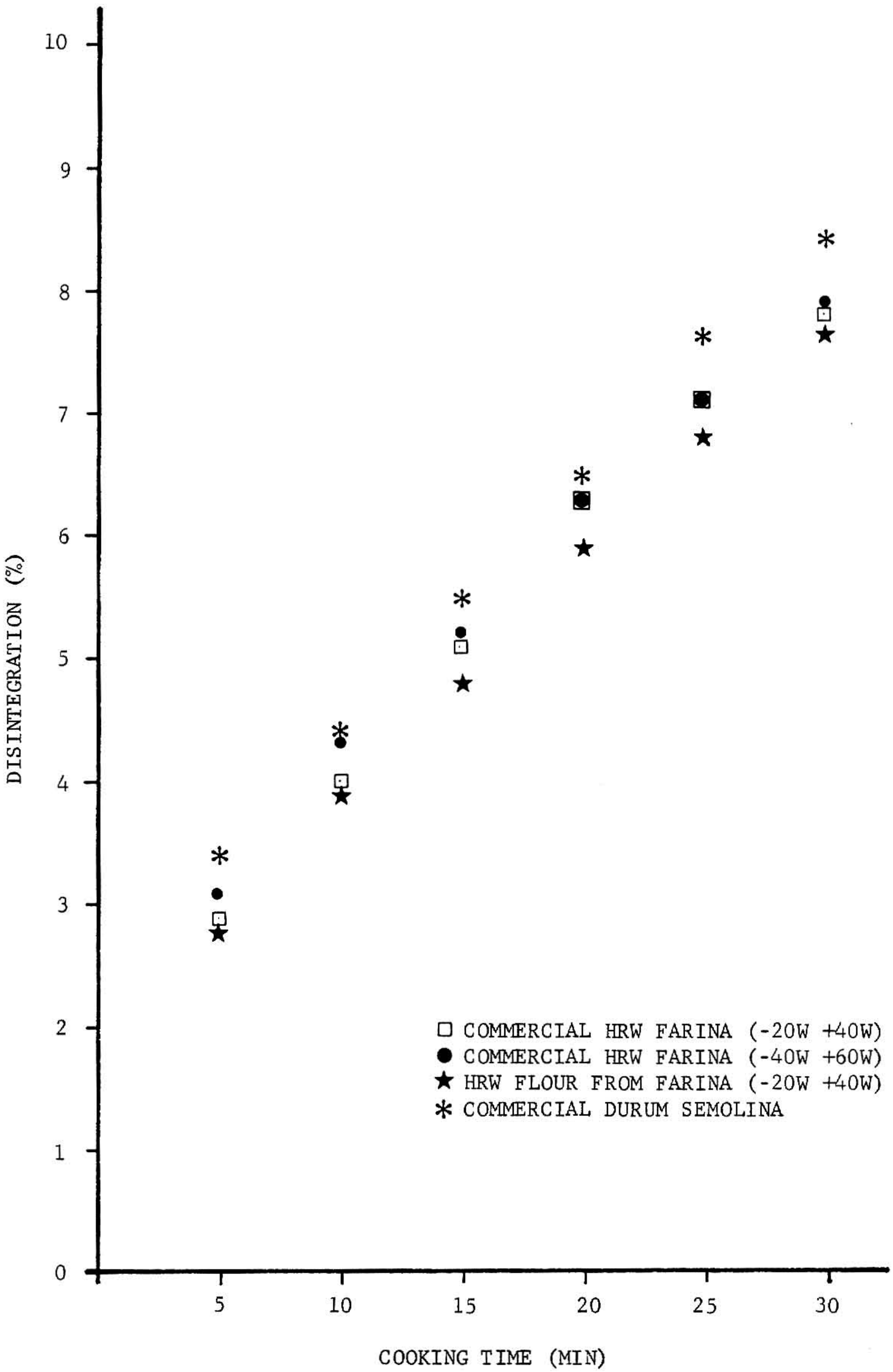

Figure 23. Disintegration During Cooking for 31.5% Original Water Absorption Spaghetti .

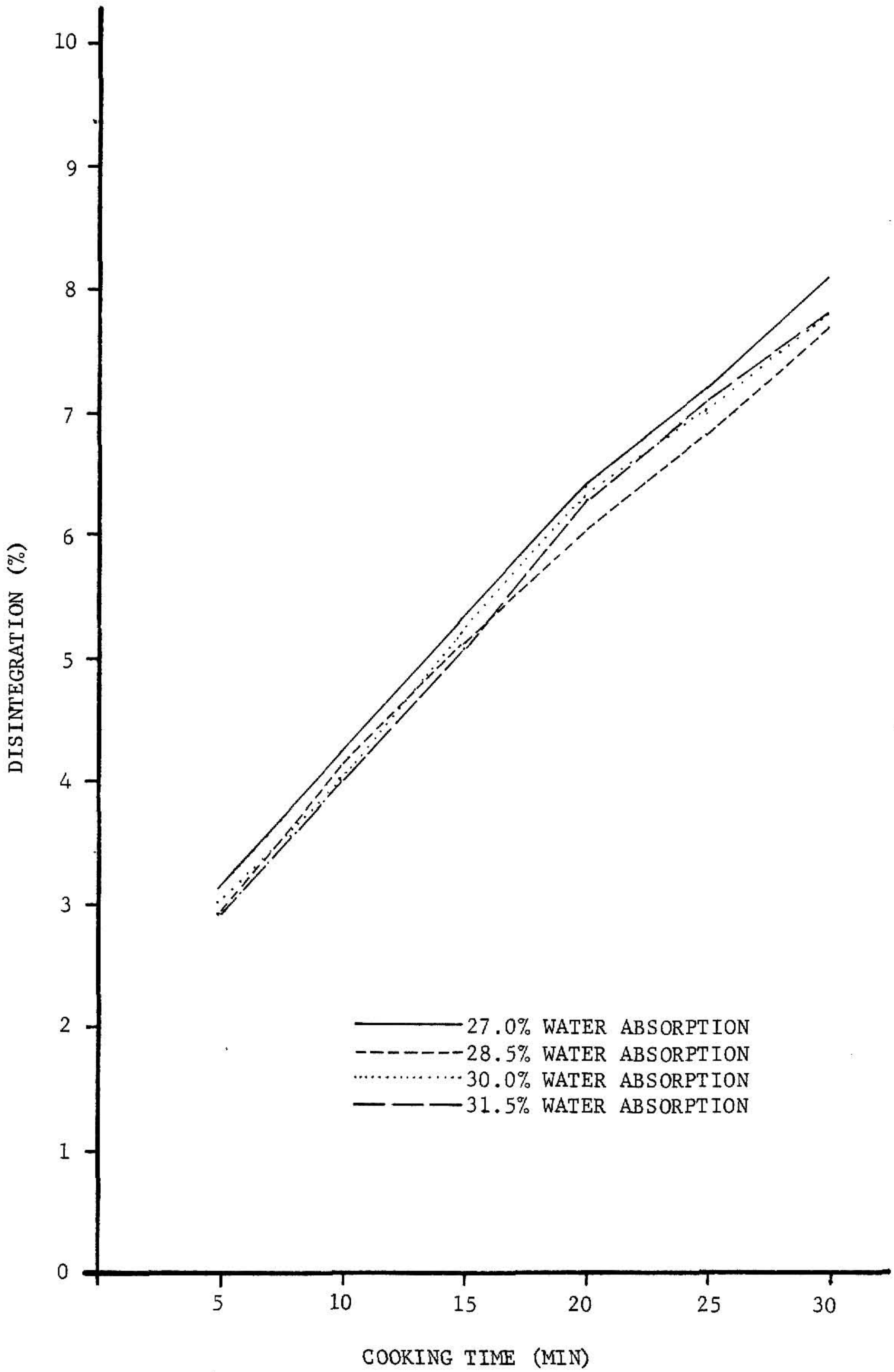

Figure 24. Effect of Original Water Absorption on Disintegration During Cooking for Commercial HRW Farina (-20W +40W).

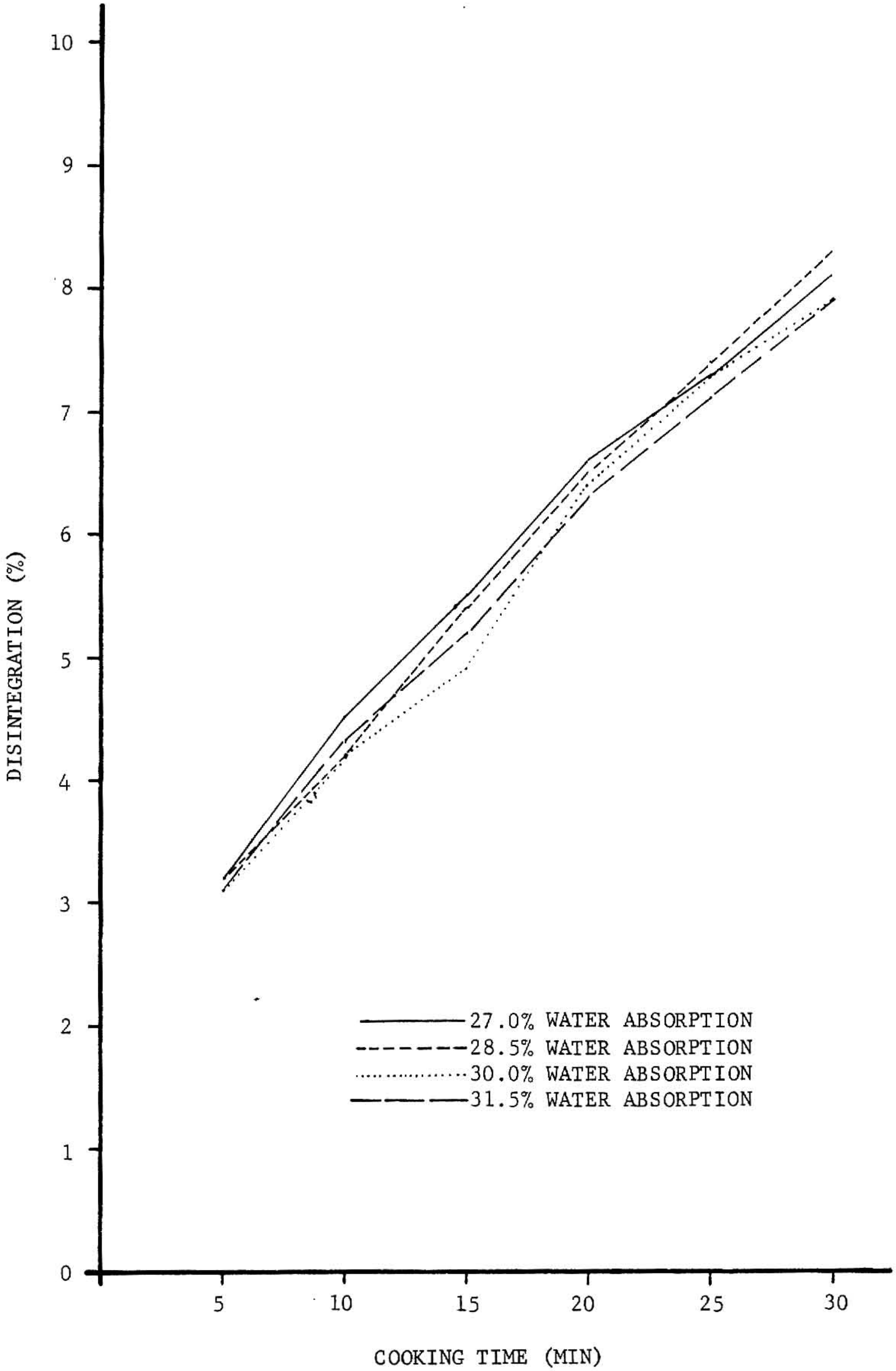

Figure 25. Effect of Original Water Absorption on Disintegration During Cooking for Commercial HRW Farina (-40W +60W).

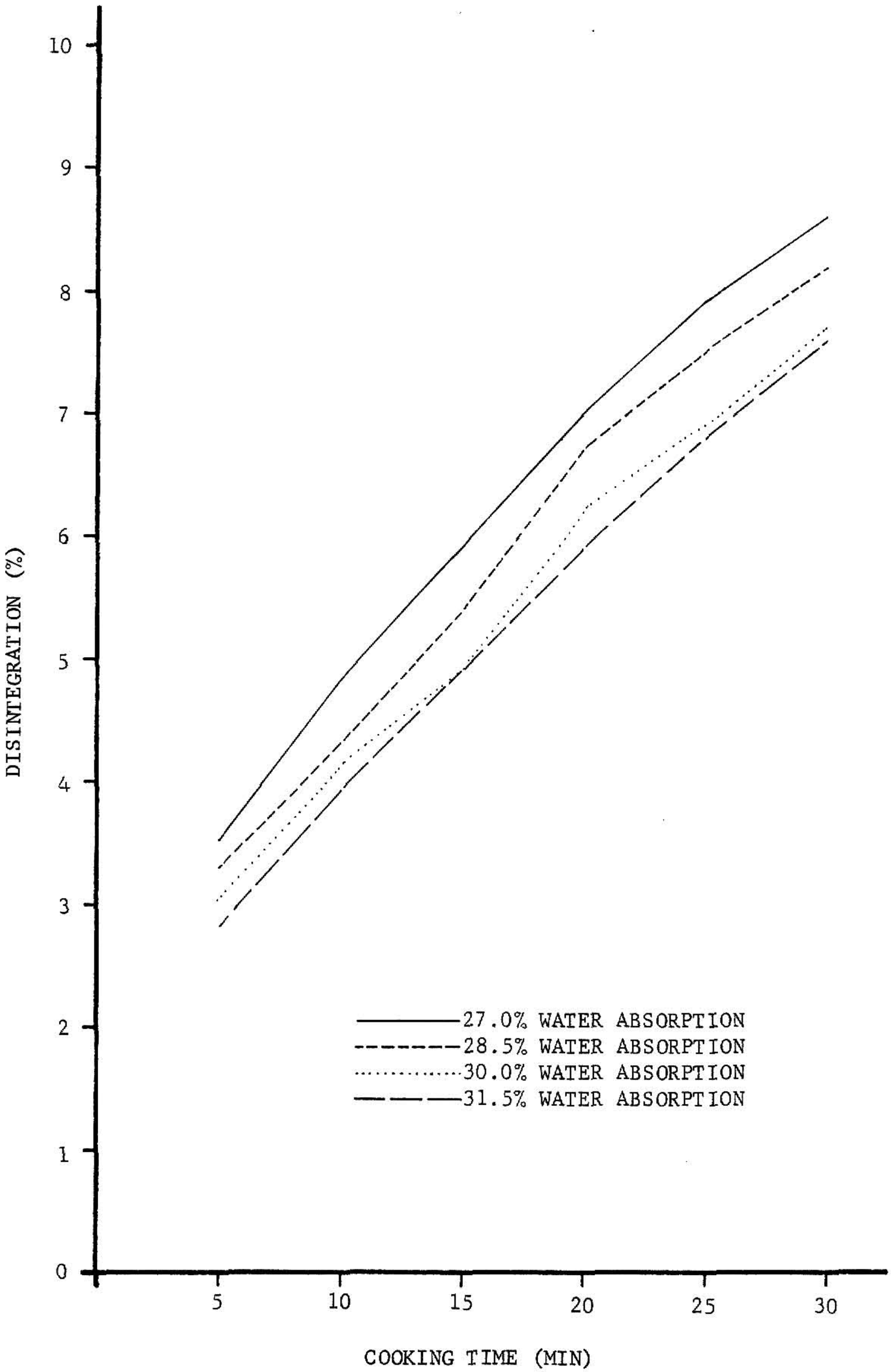

Figure 26. Effect of Original Water Absorption on Disintegration During Cooking for HRW Flour from Farina (-20W +40W).

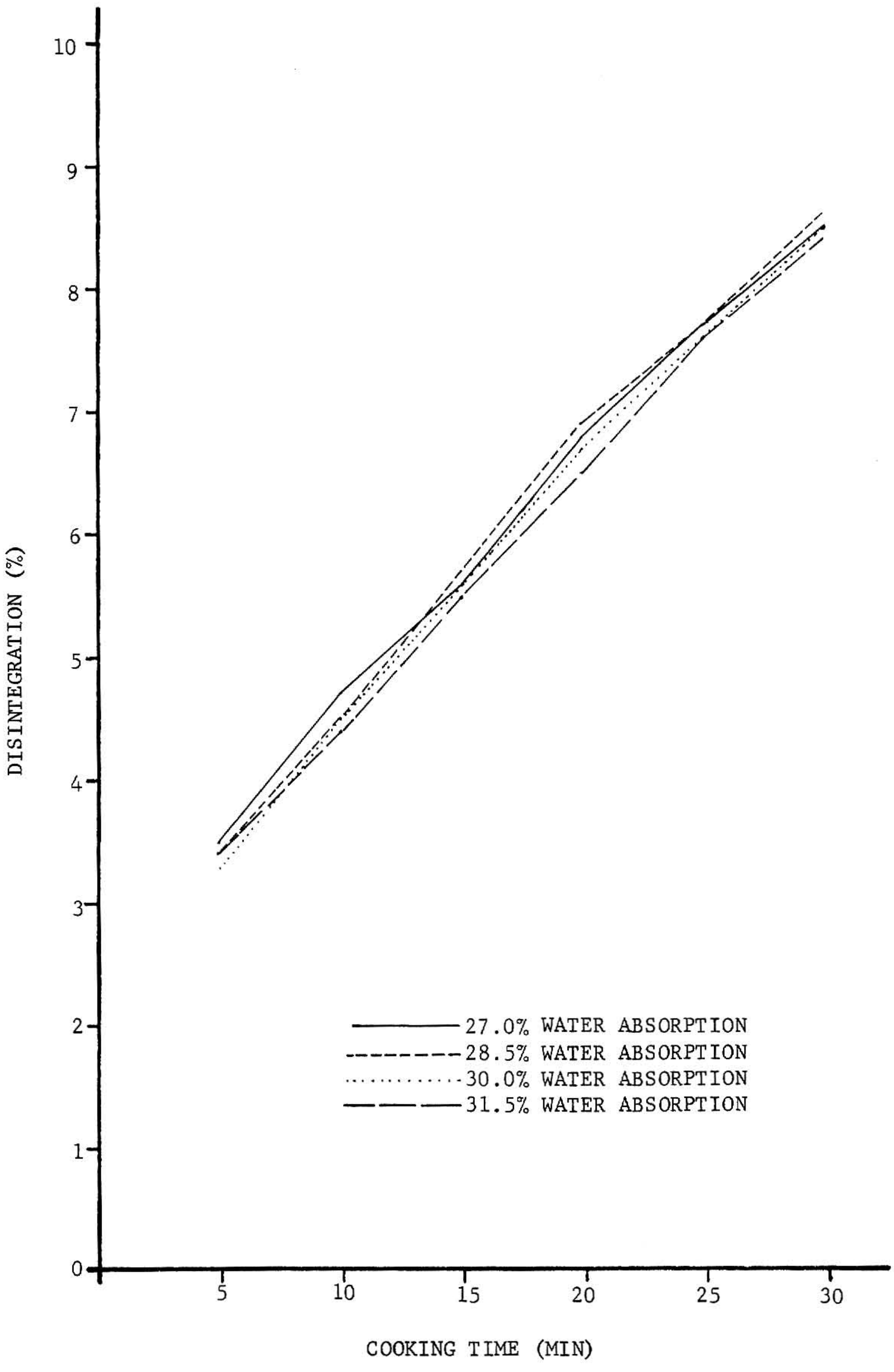

Figure 27. Effect of Original Water Absorption on Disintegration During Cooking for Commercial Durum Semolina.

TABLE VI

Disintegration During Cooking

by Products and Cooking Time (P X T Interaction)

Product	Time 5	10	15	20	25	30	$\bar{X}$	
P1	2.98	4.08	5.18	6.25	7.03	7.85	5.558	A
P2	3.15	4.30	5.25	6.45	7.28	8.05	5.745	B
P3	3.15	4.28	5.28	6.45	7.28	8.10	5.754	B
P4	3.40	4.53	5.60	6.73	7.65	8.50	6.067	C

Means with the same letter are not significantly different.

Alpha level = 0.05 DF = 45 MS error = 0.010713

TABLE VII

Disintegration of Spaghetti During Cooking

By Products and Original Absorptions (P X A Interaction)

	P1	P2	P3	P4	Mean	
A1	5.72	5.87	6.28	6.13	6.00	A
A2	5.43	5.83	5.95	6.13	5.84	B
A3	5.55	5.63	5.47	6.03	5.67	C
A4	5.53	5.65	5.31	5.97	5.62	C

Means with the same letter are not significantly different.

Alpha level = 0.05 DF = 45 MS error = 0.010713

P1 = HRW farina (-20W +40W) P2 = HRW farina (-40W +60W)
P3 = Flour from HRW farina (-20W +40W) P4 = Commercial durum semolina
A1 = 27% absorption A2 = 28.5% absorption
A3 = 30% absorption A4 = 31.5% absorption

TABLE VIII

Primary Analysis of Variance of Disintegration During Cooking Comparison of Four Products and Four Original Absorptions in Dough Preparation

Source	DF		MS	F Value	Pr > F
Product (P)	3		1.0651	99.43	0.0001
Absorption (A)	3		0.7224	67.43	0.0001
Time (T)	5		56.1198	5238.49	0.0001
T linear		1	279.4003	26080.58	0.0001
T quadratic		1	1.0131	94.57	0.0001
T cubic		1	0.0690	6.44	0.0147
Remainder		2	0.0581	5.42	
P X A	9		0.2245	20.96	0.0001
P X T	15		0.0098	0.92	0.5540
P X T linear		3	0.0311	2.90	0.0452
Remainder		12	0.0045	0.42	
A X T	15		0.0104	0.97	0.5030
A X T linear		3	0.0184	1.72	0.1770
Remainder		12	0.0084	0.78	
Error	45		0.0107		

The significant P X A interaction arises from different rankings of products in the four original water absorption levels as can be seen in Table VII. Thus at the 27% level absorption (A1) P3 is the highest and P1 the lowest in disintegration, while P2 and P4 are very close to P1 and P3, respectively. A similar ranking occurs at the 28.5% level absorption (A2) where P3 and P4 have the highest disintegrations and P1 and P2 have the lowest disintegrations.

Comparison among products (Table VI) shows that for all products the disintegration increased with cooking time. In general, the highest rate of disintegration during cooking corresponded to P4 and the lowest to P1; P2 and P3 were intermediate and essentially the same.

Finally, the results of a Duncan's Multiple Range F test of the 16 products-original absorption combinations are presented in Table IX. The means identified in this table with the same letter do not differ statistically in firmness, and thus the table results provide a mean for selecting equivalent product-original absorption combinations in terms of disintegration during cooking. HRW farina (-20W +40W) disintegration drops significantly with any increase in absorption above 27%, but disintegration does not change significantly as absorption changes from 28.5% to 20.0% to 31.5% Durum semolina disintegration is affected only by the extreme changes in absorption from 27.0% to 31.5%.

Further insight into the nature of the product by original absorption interaction can be gained through the analytical results presented in Table X. Examination of the linear, quadratic and cubic trends for each product in terms of increasing original absorption levels, showed that three of the products considered had a predominantly linear trend of disintegration with increasing original absorption; only P1 (HRW farina (-20w +40w)) appears to

TABLE IX

Duncan's Multiple Range Test for

Variable Disintegration During Cooking

Grouping	Mean	Product	Absorption
A	6.2833	3	27
B	6.1333	4	27
B	6.1333	4	28.5
B C	6.0334	4	30
C D	5.9667	4	31.5
E C D	5.9500	3	28.5
E D	5.8667	2	27
E F	5.8333	2	28.5
F G	5.7167	1	27
H G	5.6500	2	31.5
H G	5.6333	2	30
H I	5.5500	1	30
H I	5.5333	1	31.5
I	5.4667	3	30
I J	5.4333	1	28.5
J	5.3167	3	31.5

Means with the same letter are not significantly different.

Alpha level = 0.05 DF = 45 MS error = 0.010713

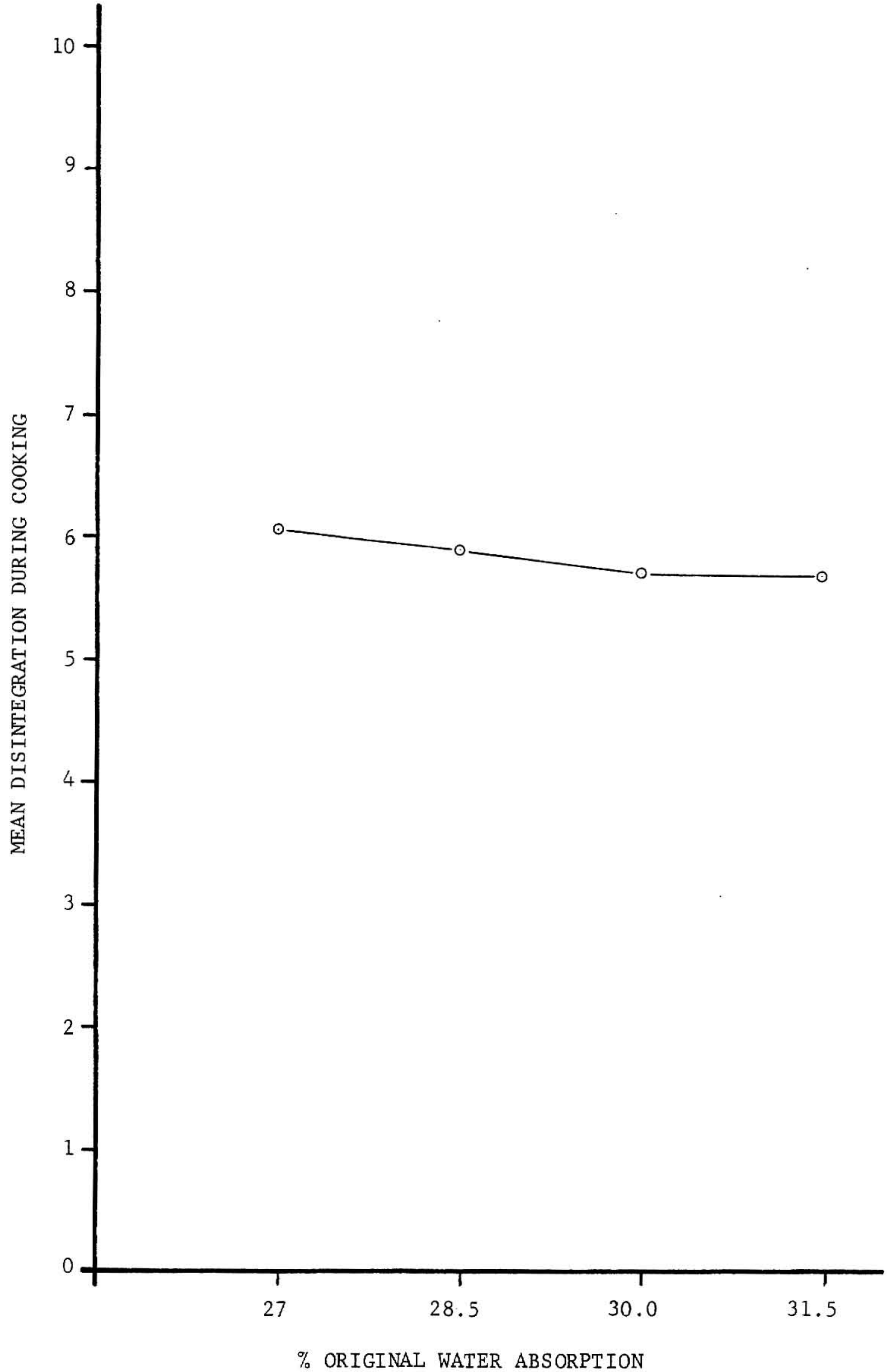

Figure 28. Mean Disintegration During Cooking for all Spaghetti,

TABLE X

Analysis of Variance for the Means

Disintegration of Spaghetti During Cooking

Product	Absorption	Mean disintegration	Mean square	Slope
P1	27	5.7167	L 0.0564	-0.0289
P1	28.5	5.4333	Q 0.1067	
P1	30.0	5.5500	C 0.0854	
P1	31.5	5.5333		
P2	27	5.8667	L 0.2168	-0.0567
P2	28.5	5.8333	Q 0.0038	
P2	30.0	5.6333	C 0.0441	
P2	31.5	5.6500		
P3	27	6.2833	L 3.4336	-0.2255
P3	28.5	5.9500	Q 0.0504	
P3	30.0	5.4667	C 0.0701	
P3	31.5	5.3167		
P4	27	6.1333	L 0.1079	-0.0400
P4	28.5	6.1333	Q 0.0067	
P4	30.0	6.0333	C 0.0053	
P4	31.5	5.9667		

deviate from this pattern giving some evidence of curvature. The results are depicted graphically in Fig. 29.

Since, as previously stated, there is no evidence of either product X time (P x T) or absorption X time (A x T) interactions, the time trends previously discussed with cooking time hold regardless of product and level of absorption.

Water Absorption of Spaghetti During Cooking

The water absorption of spaghetti during cooking data for the four products and four different absorptions is shown in Table XI. The means over the products original absorption* and time presented in Tables XII, XIII and XIV help in understanding the nature of the absorption x time, product x time and absorption x product interactions, respectively. The time trends in water absorption during cooking with cooking time are illustrated by original absorptions in Fig. 30 through 33 and by products in Fig. 34 through 37.

The results of the primary analysis of variance for water absorption of spaghetti during cooking (data of Table XI) presented in Table XV, show that product, original absorption and cooking time have a significant effect on the water absorption of spaghetti during cooking, with only the product x time (P x T) and product x absorption (PxA) interactions showing significance.

The overall comparison among products without reference either to original absorption or cooking time (Table XIII) shows significant differences ($P \leq 0.05$) among products with the commercial durum semolina (P4) having the highest absorption during cooking.

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*% of water added in preparing the dough in the spaghetti preparation.

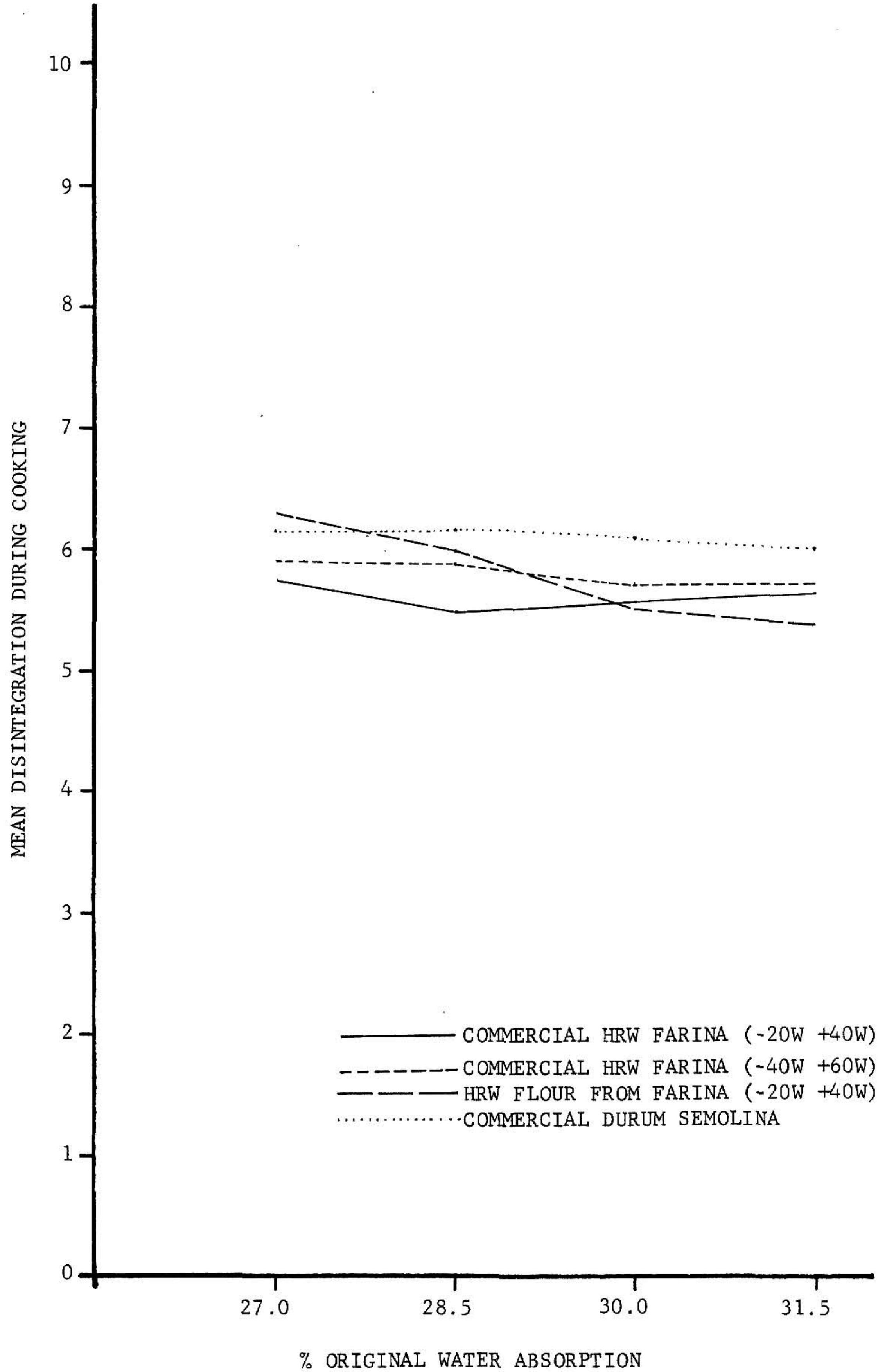

Figure 29. Mean Disintegration During Cooking of All Spaghetti at Different Absorptions.

The overall comparison among original absorptions without reference to either product or cooking time (Table XIV) shows significant differences ($P \leq 0.05$) in water absorbed during cooking with rankings in the same order as the original water absorption for the dough preparation (original absorption) in manufacturing the spaghetti. The increase in percent of water absorption absorbed during cooking with increasing percent of water absorption in preparing the spaghetti is significant and essentially linear (Table XIV) with a definite downward curvature which suggests that a maximum cooking absorption is approached as illustrated in Fig. 38. The significant product x absorption interaction arises from different ranking of products in the four original water absorption levels as can be seen in Table XIV. Thus, at the 27% original absorption level, P4 is the highest and P3 the lowest in cooking water absorption, while P1 and P2 are intermediate and not statistically different. The same ranking of products holds at 28.5% original absorption but in this case all products differ statistically in terms of water absorbed during cooking. The product rankings change in the two higher levels of original absorptions, considered ranking P4, P2, P1, and P3, from high to low, in that order, at the 30% level and P2, P4, P1 and P3 from high to low at the 31.5% original absorption level. On the average, however, P4 appears higher and P3 lower.

Comparisons among products (Table XIII) show that for all products the water absorbed increased with cooking time, but as illustrated in Fig. 39 this occurred at different rates and different levels, thus the significant product x time interaction. In general, the highest rate of water absorption during cooking corresponded to P4 and the lowest to P3; P1 and P2 were intermediate and essentially the same. In other words, the time trends of water absorption during cooking for the four products

TABLE XI

Water Absorption During Cooking (%)

Absorption %		Cooking time 5 Min	10 Min	15 Min	20 Min	25 Min	30 Min	$\bar{X}$
27	Commercial HRW farina (-20W +40W)	69.9	114.0	141.8	175.1	206.5	230.3	156.27
27	Commercial HRW farina (-40W +60W)	64.8	110.2	139.0	177.1	208.7	234.0	155.63
27	HRW Flour from farins (-20W +40W)	63.0	101.1	130.3	166.8	201.7	222.5	147.52
27	Commercial durum semolina	72.0	119.0	148.7	179.3	222.1	249.8	165.15
28.5	Commercial HRW farina (-20W +40W)	72.3	115.3	148.7	172.0	209.8	236.3	159.07
28.5	Commercial HRW farina (-40W +60W)	74.1	120.4	151.9	181.3	214.0	239.7	163.57
28.5	HRW Flour from Farina (-20W +40W)	65.3	104.0	140.0	168.7	201.1	223.0	150.35
28.5	Commercial durum semolina	79.4	130.9	155.3	186.6	221.7	255.8	171.62
30	Commercial HRW farina (-20W +40W)	75.9	118.7	149.5	173.2	218.1	240.0	162.57
30	Commercial HRW farina (-40W +60W)	77.1	120.3	154.7	188.2	214.1	237.8	165.37
30	HRW Flour from farina (-20W +40W)	71.9	117.1	146.3	182.2	205.3	231.5	159.05
30	Commercial durum semolina	80.3	122.4	152.5	191.2	224.7	259.9	171.83
31.5	Commercial HRW farina (-20W +40W)	71.8	120.3	154.4	190.0	218.4	242.0	166.15
31.5	Commercial HRW farina (-40W +60W)	77.9	128.0	163.1	187.6	220.3	251.3	171.37
31.5	HRW Flour from farina (-20W +40W)	74.3	118.9	151.7	183.3	211.2	238.8	163.03
31.5	Commercial durum semolina	75.8	126.3	156.1	189.2	216.8	246.1	168.38

TABLE XII

Water Absorption of Spaghetti During Cooking by Original Absorption and Cooking Time (A X T Interaction)

	Time (min)							
Absorption	5	10	15	20	25	30	$\bar{X}$	
27%	67.43	111.08	139.88	174.58	209.75	234.15	156.14	A
28.5%	76.30	119.63	150.75	183.70	215.55	242.30	161.15	B
30.0%	72.78	117.65	148.98	177.15	211.65	238.70	164.70	C
31.5%	74.95	123.38	156.33	187.53	216.68	244.55	167.23	D

Means with the same letter are not significantly different.

Alpha level = 0.05 DF = 45 MS error = 9.82489

TABLE XIII

Water Absorption of Spaghetti During Cooking By Product and Cooking Time (P X T Interaction)

	Time (min)							
Product	5	10	15	20	25	30	$\bar{X}$	
P1	72.475	117.075	148.600	177.575	213.200	237.150	161.013	A
P2	73.475	119.725	152.175	183.550	214.275	240.700	163.983	B
P3	68.625	110.275	142.000	175.250	204.825	228.950	154.988	C
P4	76.875	124.650	153.150	186.575	221.325	252.900	169.246	D

Means with the same letter are not significantly different.

Alpha level = 0.05 DF = 45 MS error = 9.82482

TABLE XIV

Water Absorption of Spaghetti During Cooking

By Product and Original Absorption (P X A Interaction)

	P_1	P_2	P_3	P_4	Mean	
A_1	156.27	155.63	147.52	165.15	156.14	A
A_2	159.07	163.57	150.35	171.62	161.15	B
A_3	162.57	165.37	159.05	171.83	164.70	C
A_4	166.15	171.37	163.03	168.38	167.23	D

Means with the same letter are not significantly different.

Alpha level = 0.05 DF = 45 MS error = 9.82489

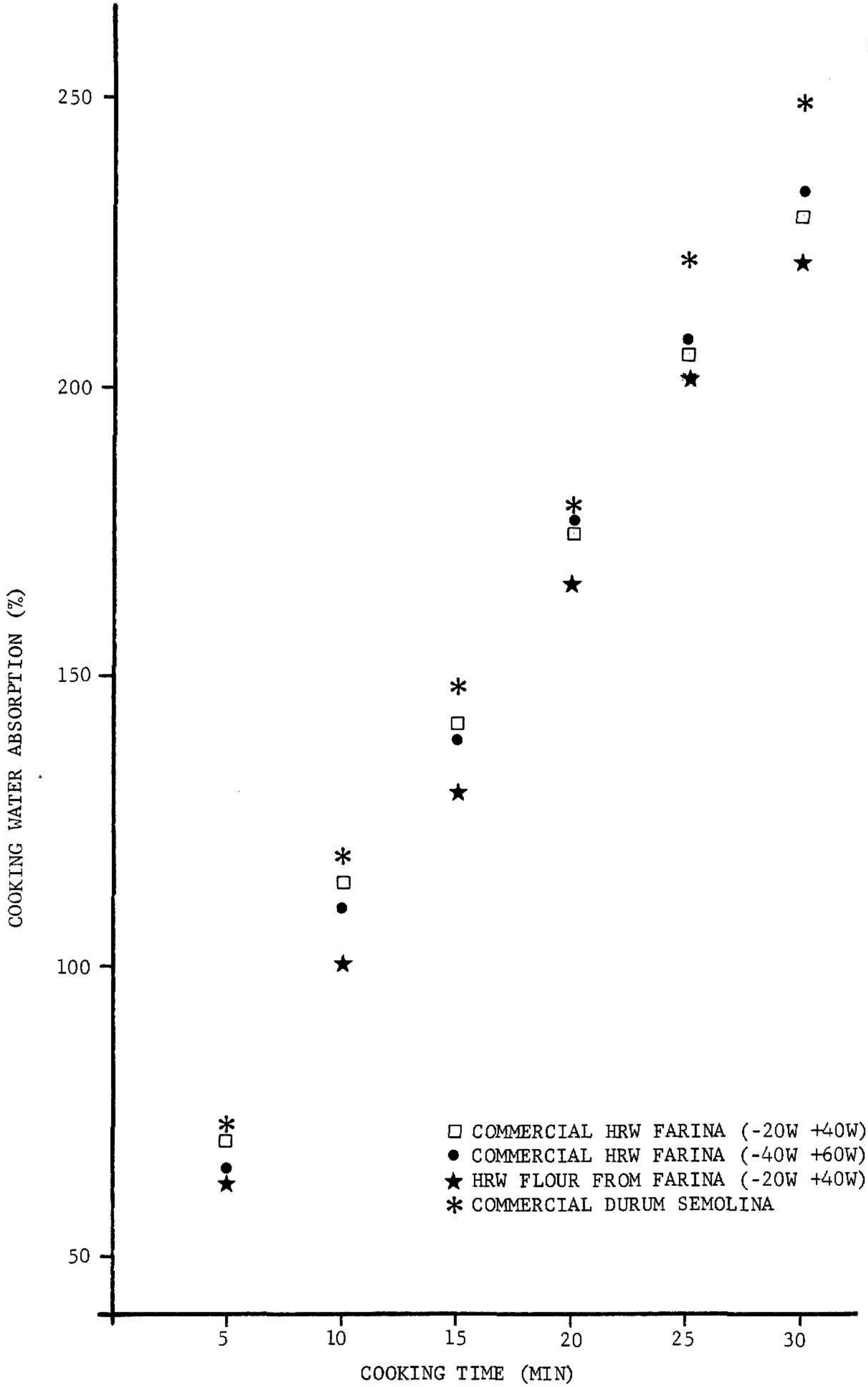

Figure 30. Water Absorption During Cooking for the 27% Original Water Absorption Spaghetti.

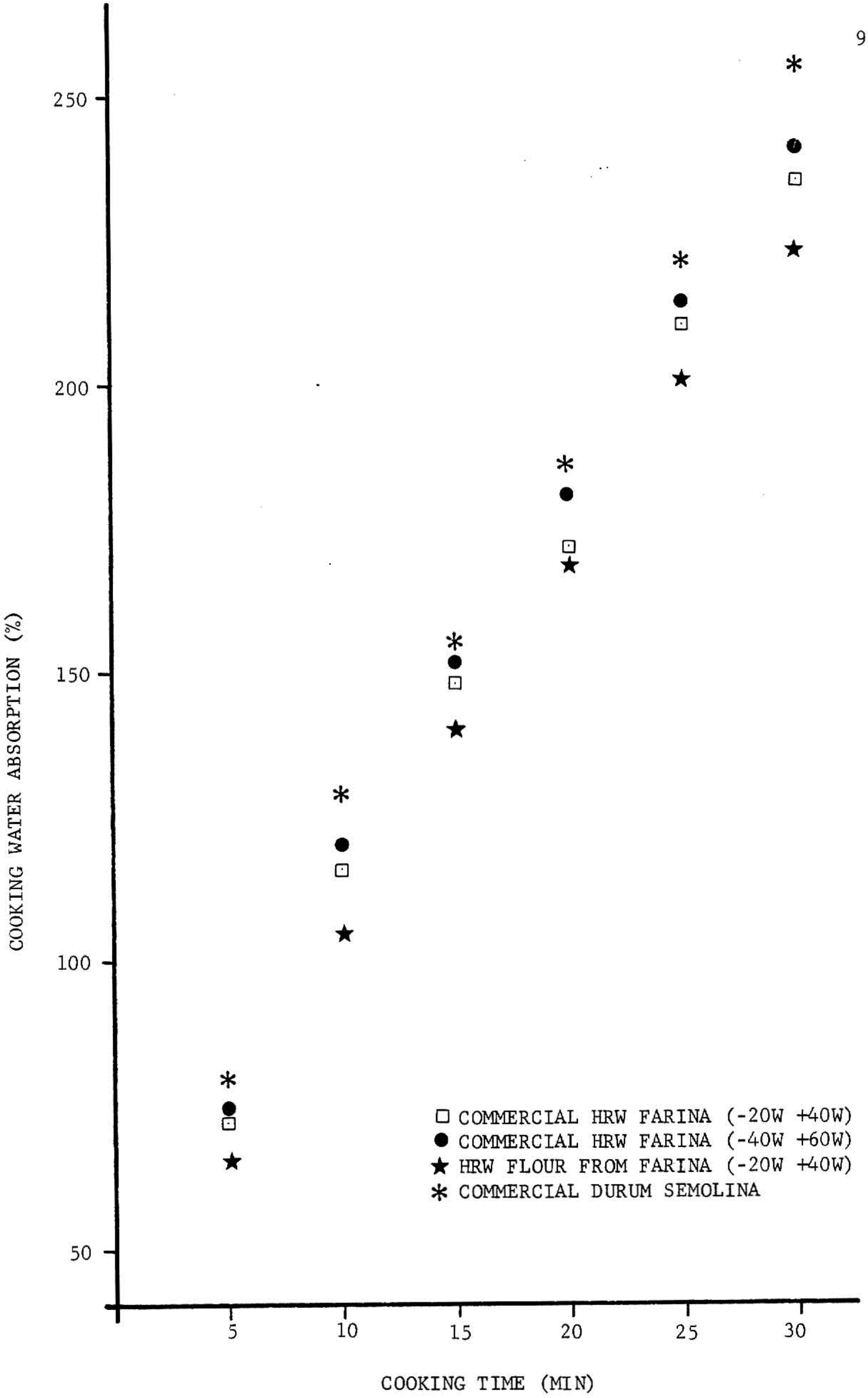

Figure 31. Water Absorption During Cooking for the 28.5% Original Water Absorption Spaghetti.

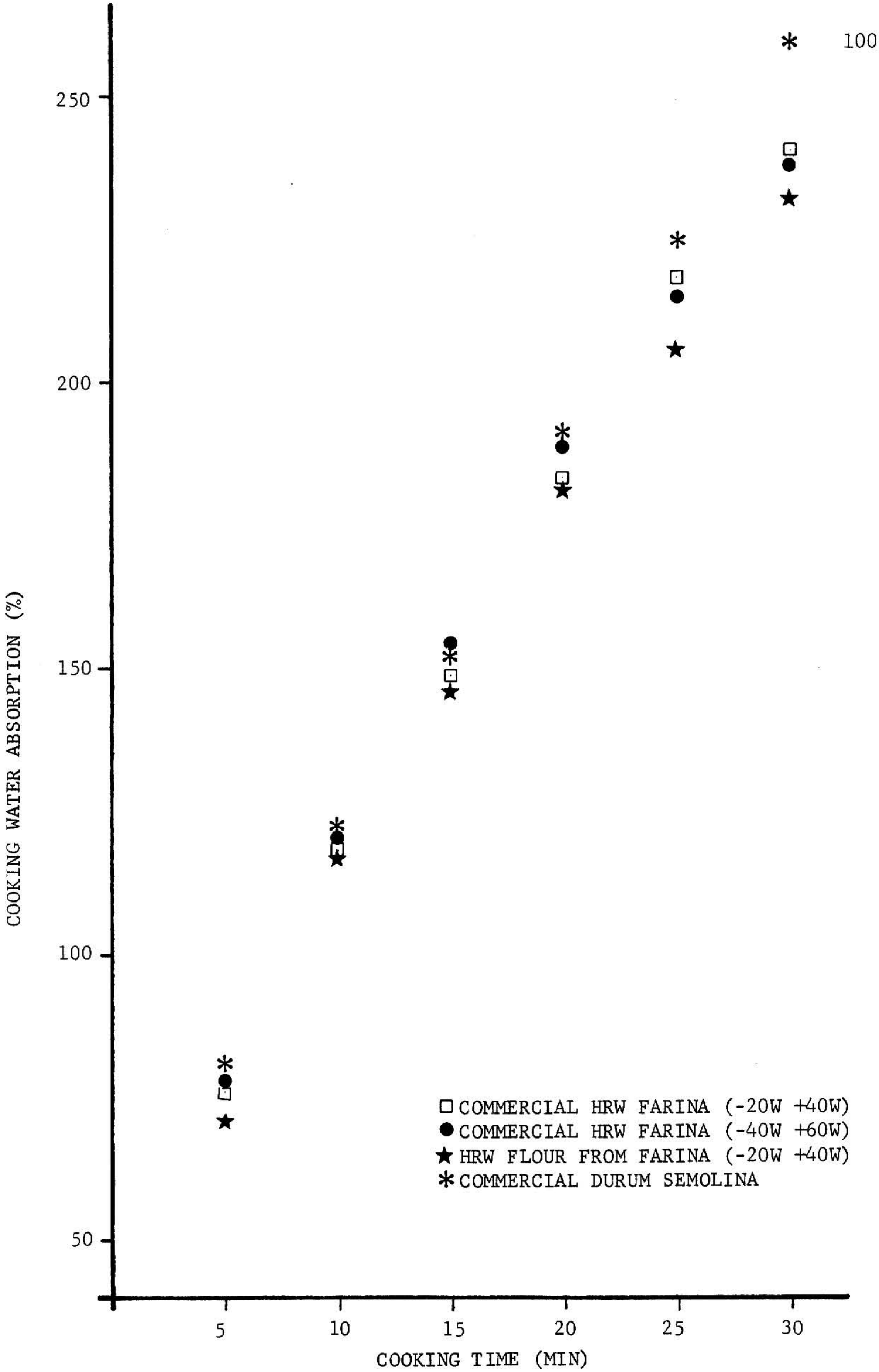

Figure 32. Water Absorption During Cooking for the 30.0% Original Water Absorption Spaghetti.

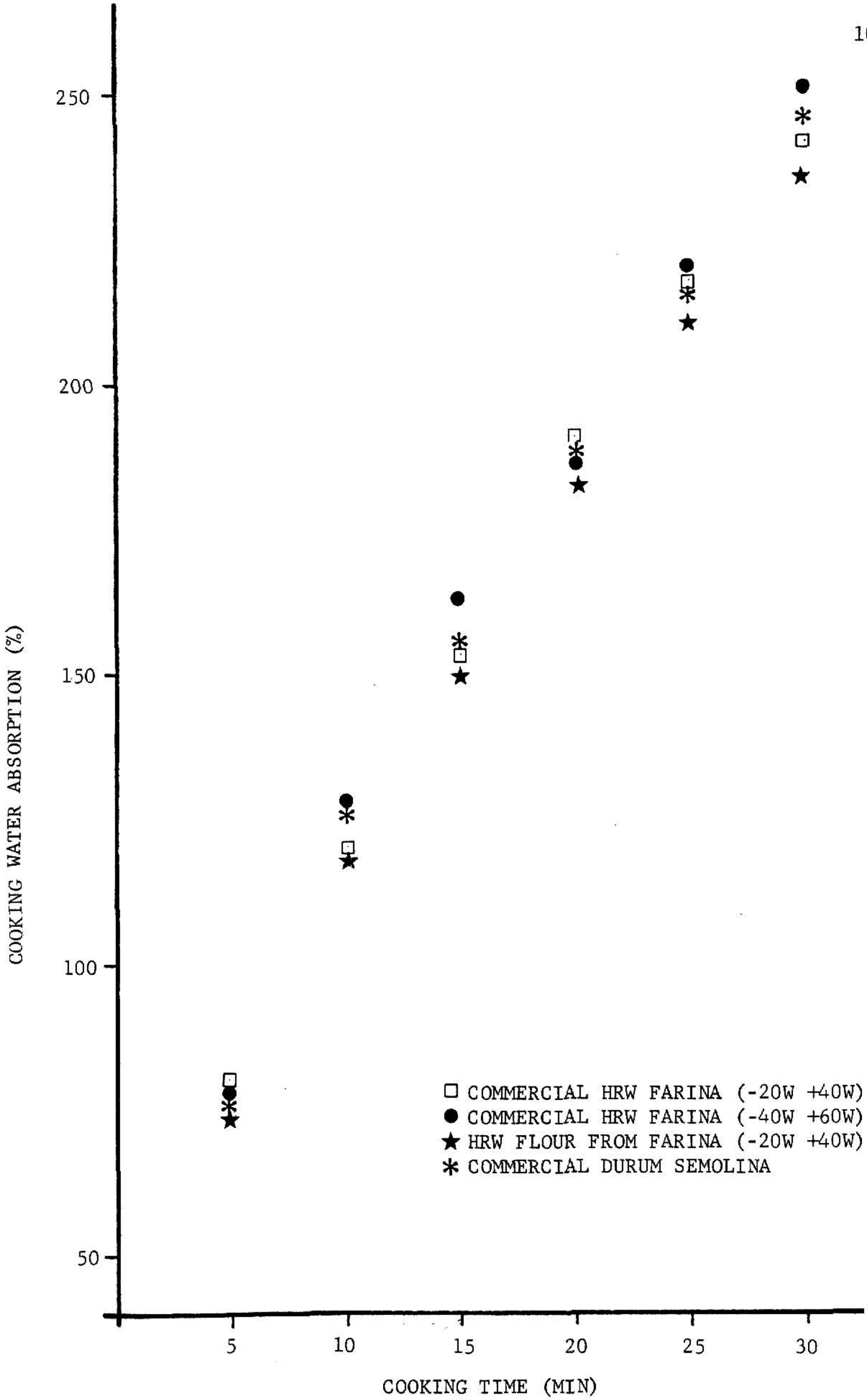

Figure 33. Water Absorption During Cooking for the 31.5% Original Water Absorption Spaghetti.

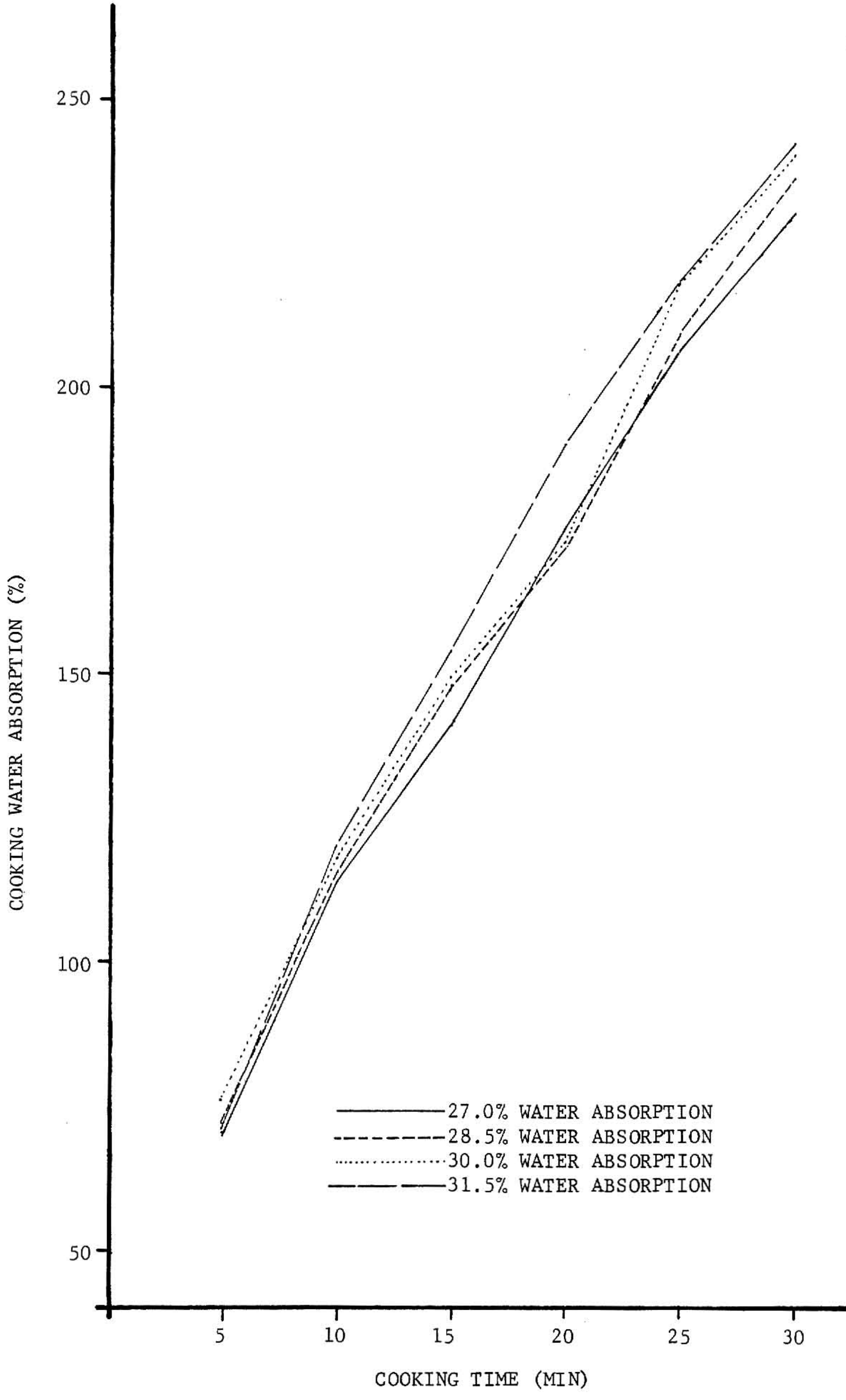

Figure 34. Effect of Original Water Absorption on Water Absorption During Cooking for Commercial HRW Farina (-20W +40W).

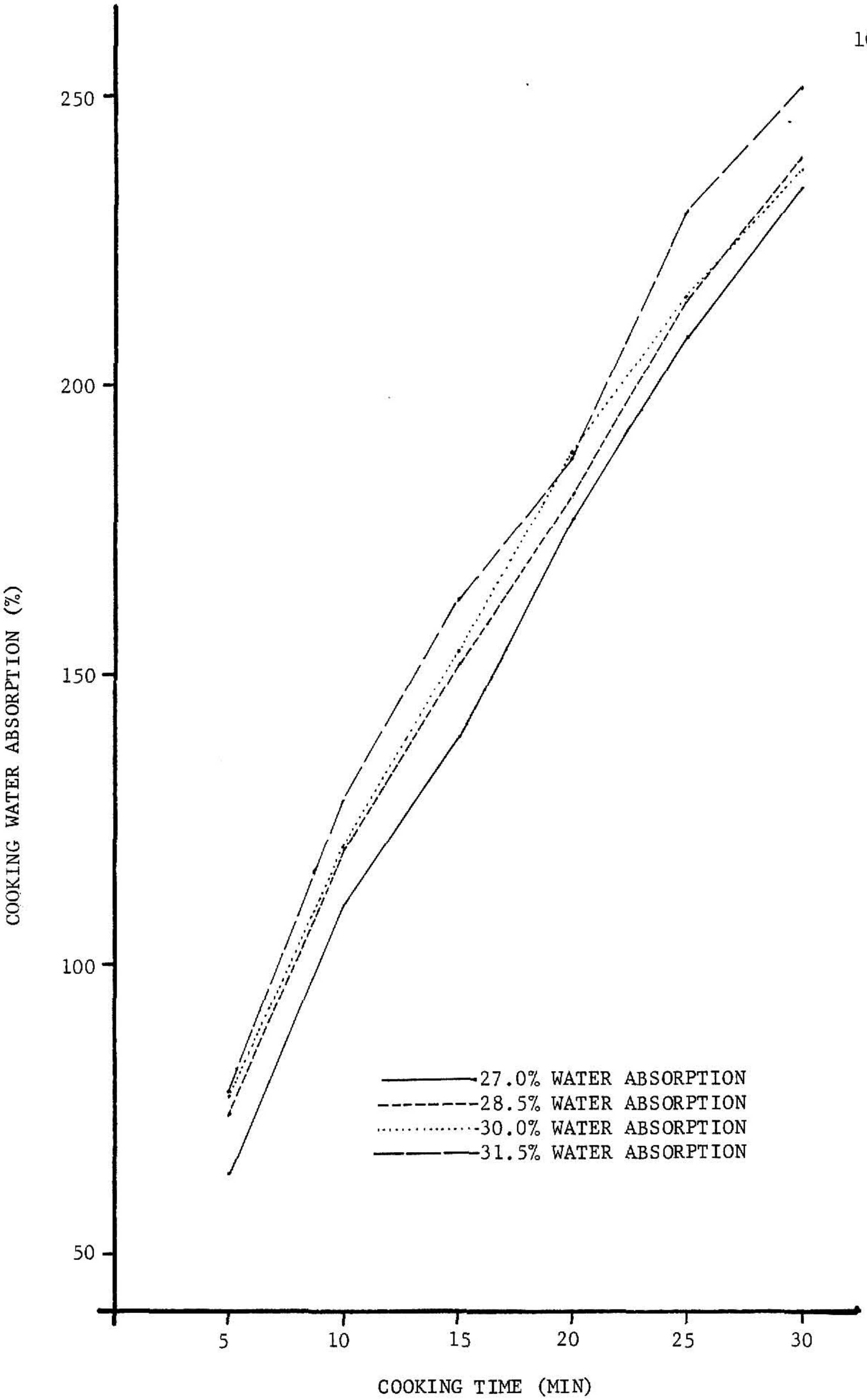

Figure 35. Effect of Original Water Absorption on Water Absorption During Cooking for Commercial HRW Farina (-40W +60W).

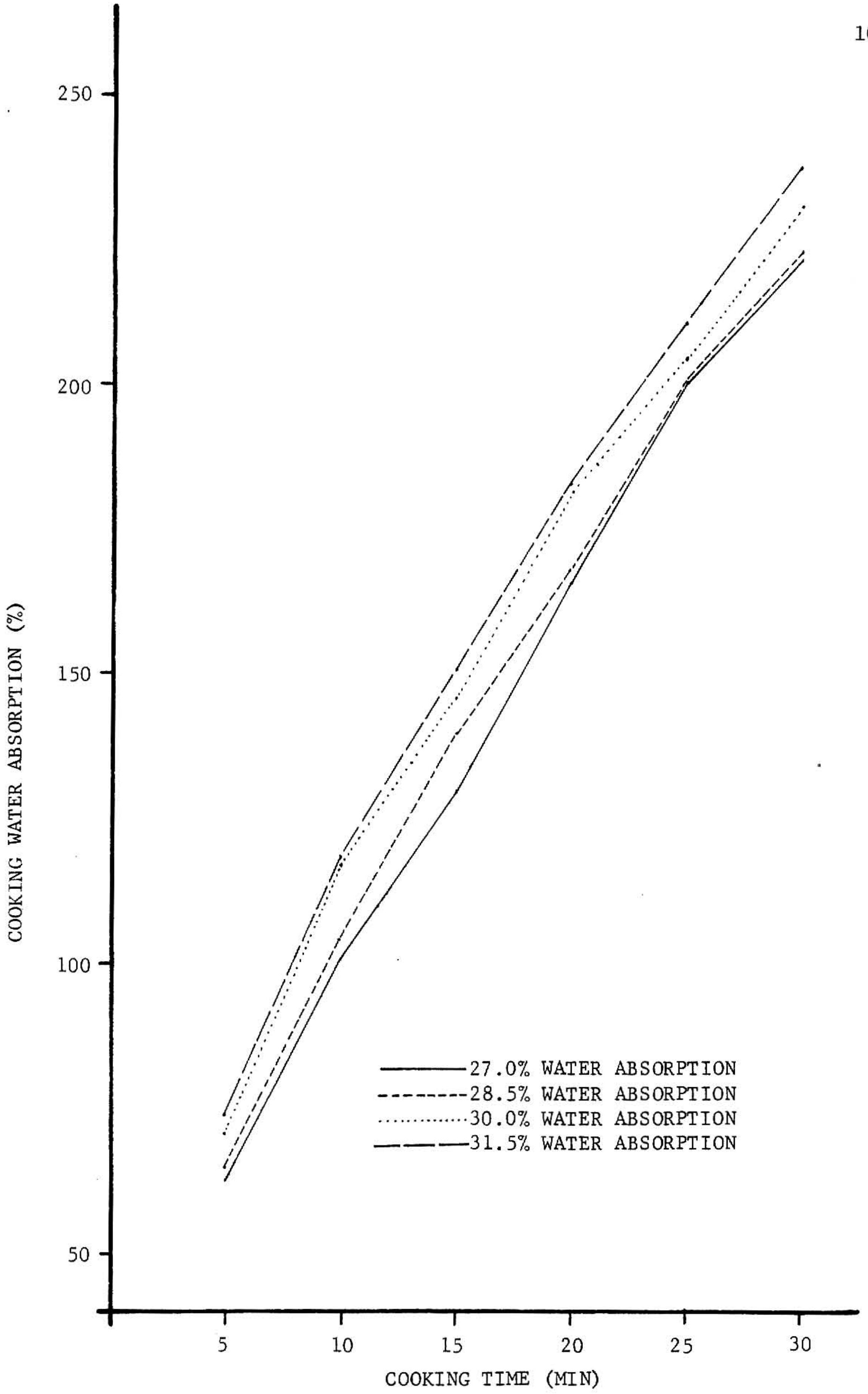

Figure 36. Effect of Original Water Absorption on Water Absorption During Cooking for HRW Flour from Farina (-20W +40W).

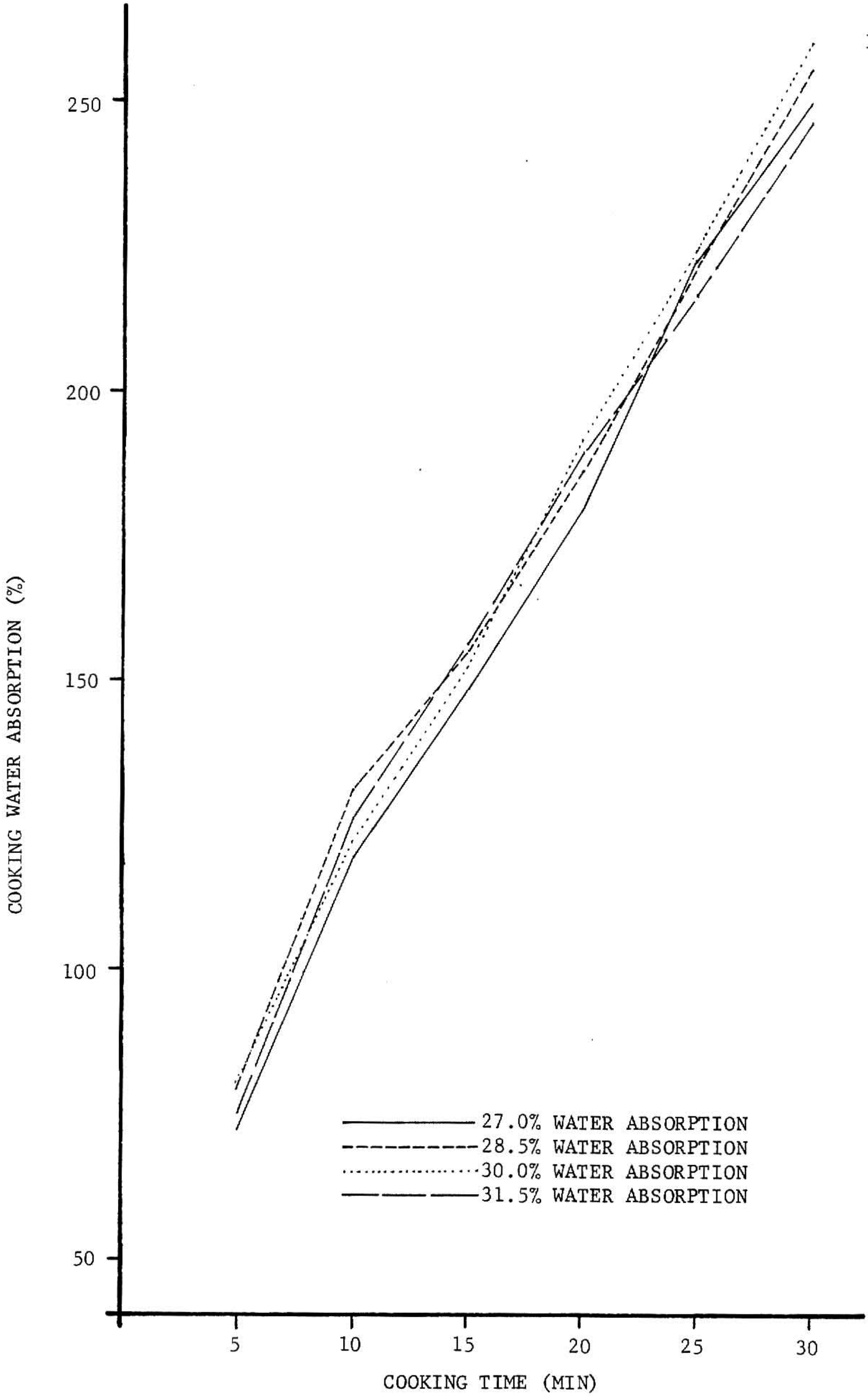

Figure 37. Effect of Original Water Absorption on Water Absorption During Cooking for Commercial Durum Semolina.

TABLE XV

Primary Analysis of Variance of Water Absorption of Spaghetti During Cooking and Comparison of Four Products and Four Original Absorptions in Dough Preparation

Source	DF		MS	F Value	Pr > F
Product (P)	3		849.6665	86.48	0.0001
Absorption (A)	3		554.9212	56.48	0.0001
Time (T)	5		61191.9103	6228.56	0.0001
T linear		1	304125.2186	30954.56	0.0001
T quadratic		1	1417.9557	144.31	0.0001
T cubic		1	141.9557	14.45	0.0004
Remainder		2	137.2958	13.97	0.0001
P X A	9		61.5841	6.27	0.0001
P X T	15		26.0931	2.66	0.0058
P X T linear		3	74.2758	7.56	0.0003
Remainder		12	14.0474	1.43	
A X T	15		12.9171	1.31	0.2334
A X T linear		3	6.5614	0.67	0.5762
Remainder		12	14.5061	1.48	
Error	45		9.8249		

considered are not parallel. The range of cooking water absorbed after 5 minutes of cooking was 8.25% (76.88 P4 - 68.62 P3) while the range after 30 minutes of cooking was 23.95% (252.90 P4 - 228.95 P3), approximately three times the initial value.

Finally, the results of a Duncan's Multiple Range F test of the 16 product-original absorption combinations are presented in Table XVI. The means identified in this table, with the same letter, do not differ statistically in water absorbed during cooking, and thus the table results provide a means for selecting equivalent product-original absorption combinations in terms of water absorption during cooking.

Similarly, further insight in the nature of the product x time interaction can be gained through the analysis presented in Table XVII. In this case all the trends in water absorption during cooking are predominantly linear, accounting for over 99% of the sum of squares among cooking times for each product with no evidence of curvature in these trends. The trends, however, occur at different rates ranging from 6.39% per minute in the case of P3 and to a high 6.88% per minute for P4. P1 and P2 have intermediate similar trends 6.52% and 6.58% per minute, respectively. These results are illustrated in Fig. 39.

Further insight into the nature of the product by original absorption interaction can be gained through the analytical results presented in Table XVIII. In this case the general trend in water absorption during cooking is examined by products in terms of linear, quadratic and cubic components. In the case of P1, P2, and P3, the increasing trends in water absorbed during cooking by original absorption occur at different rates but are essentially linear, and a linear fit in this case would account for over 95% of the sum of squares among original absorptions for these products.

TABLE XVI

Duncan's Multiple Range Test for

Variable Water Absorption During Cooking

Grouping	Mean	Product	Absorption
A	171.8333	4	30.0
A	171.6167	4	28.5
A	171.3667	2	31.5
B A	168.3833	4	31.5
B C	166.1500	1	31.5
B C	165.3667	2	30.0
B C	165.1500	4	27.0
C	163.5667	2	28.5
C	163.0333	3	31.5
D C	162.5667	1	30.0
D E	159.0667	1	28.5
D E	159.0500	3	30.0
E	156.2667	1	27.0
E	155.6333	2	27.0
F	150.3500	3	28.5
F	147.5167	3	27.0

Means with the same letter are not significantly different.

Alpha level = 0.05 DF = 45 MS error = 9.82489

TABLE XVII

Analysis of Variance for the Mean Water Absorption of Spaghetti (P X T Interaction)

Product	Time	Mean water absorption	Mean square	Slope
P1	5	72.475	L 74357.3443	6.52
P1	10	117.075		
P1	15	148.600		
P1	20	177.575	Q 359.1868	
P1	25	213.200	C 26.6036	
P1	30	237.150		
P2	5	73.4750	L 75722.6470	6.58
P2	10	119.725	Q 535.3000	
P2	15	152.175		
P2	20	183.550	C 52.8667	
P2	25	214.275		
P2	30	240.700		
P3	5	68.625	L 71491.3243	6.39
P3	10	110.275		
P3	15	142.000	Q 440.9167	
P3	20	175.250		
P3	25	204.825	C 1.0200	
P3	30	228.950		
P4	5	76.875	L 82776.7303	6.88
P4	10	124.650		
P4	15	153.150	Q 149.3333	
P4	20	186.575		
P4	25	221.325	C 107.9576	
P4	30	252.900		

TABLE XVIII

Analysis of Variance for the Mean Water Absorption of Spaghetti (P X A Interaction)

Product	Absorption	Mean water absorption	Mean square	Slope
P1	27.0	156.2667	L 329.6748	2.21
P1	28.5	159.0667		
P1	30.0	162.5667	Q 0.9203	
P1	31.5	166.1500	C 0.1141	
P2	27.0	155.6333	L 720.3059	3.27
P2	28.5	163.5667		
P2	30.0	165.3667	Q 5.6071	
P2	31.5	171.3667	C 32.0337	
P3	27.0	147.5167	L 915.7621	3.68
P3	28.5	150.3500		
P3	30.0	159.0500	Q 1.9838	
P3	31.5	163.0333	C 33.6025	
P4	27.0	165.1500	L 29.5011	0.66
P4	28.5	171.6167		
P4	30.0	171.8333	Q 147.5114	
P4	31.5	168.3833	C 2.0023	

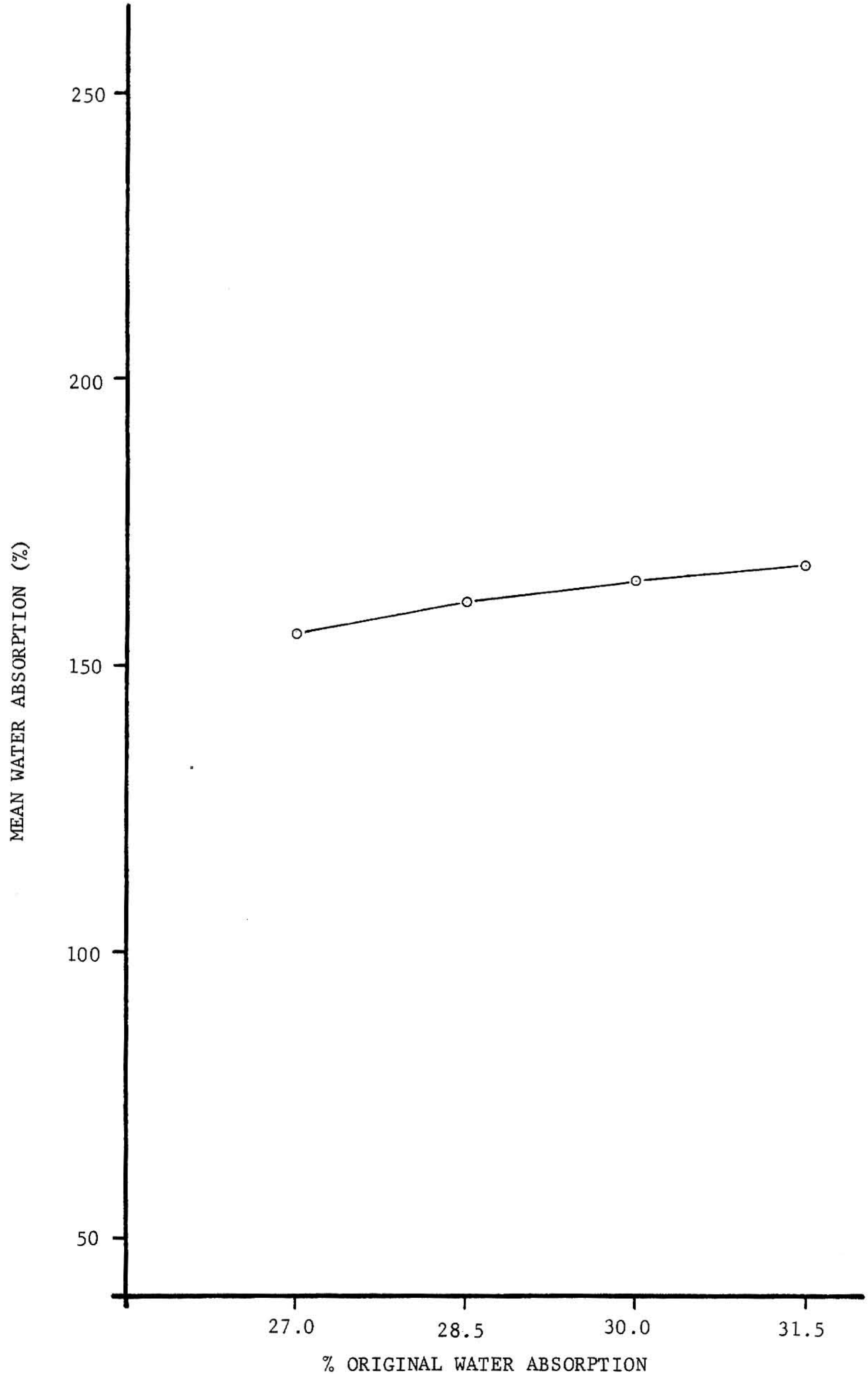

Figure 38. Mean Water Absorption During Cooking of All Spaghetti .

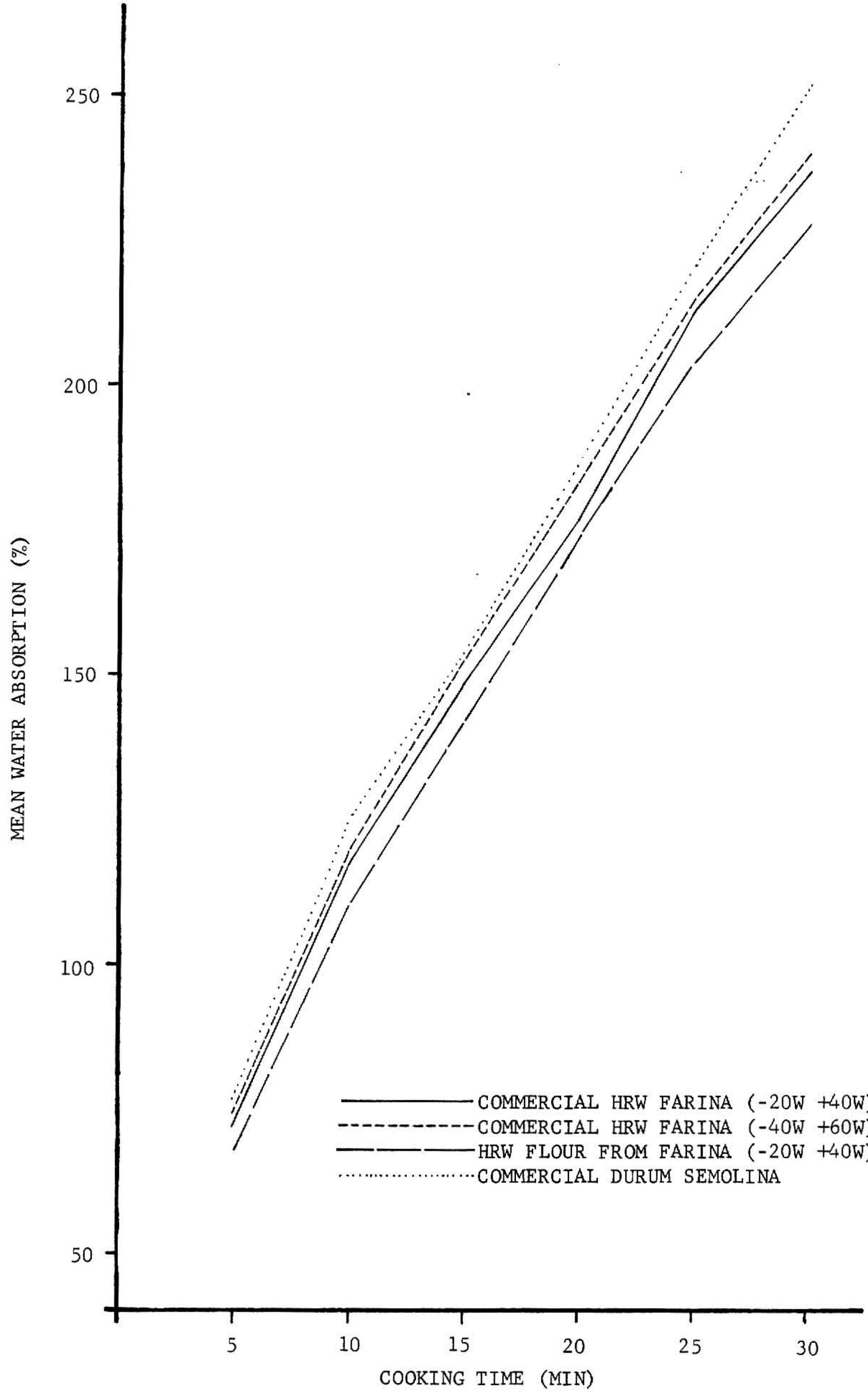

Figure 39. Mean Water Absorption During Cooking of All Original Water Absorptions for Each Product.

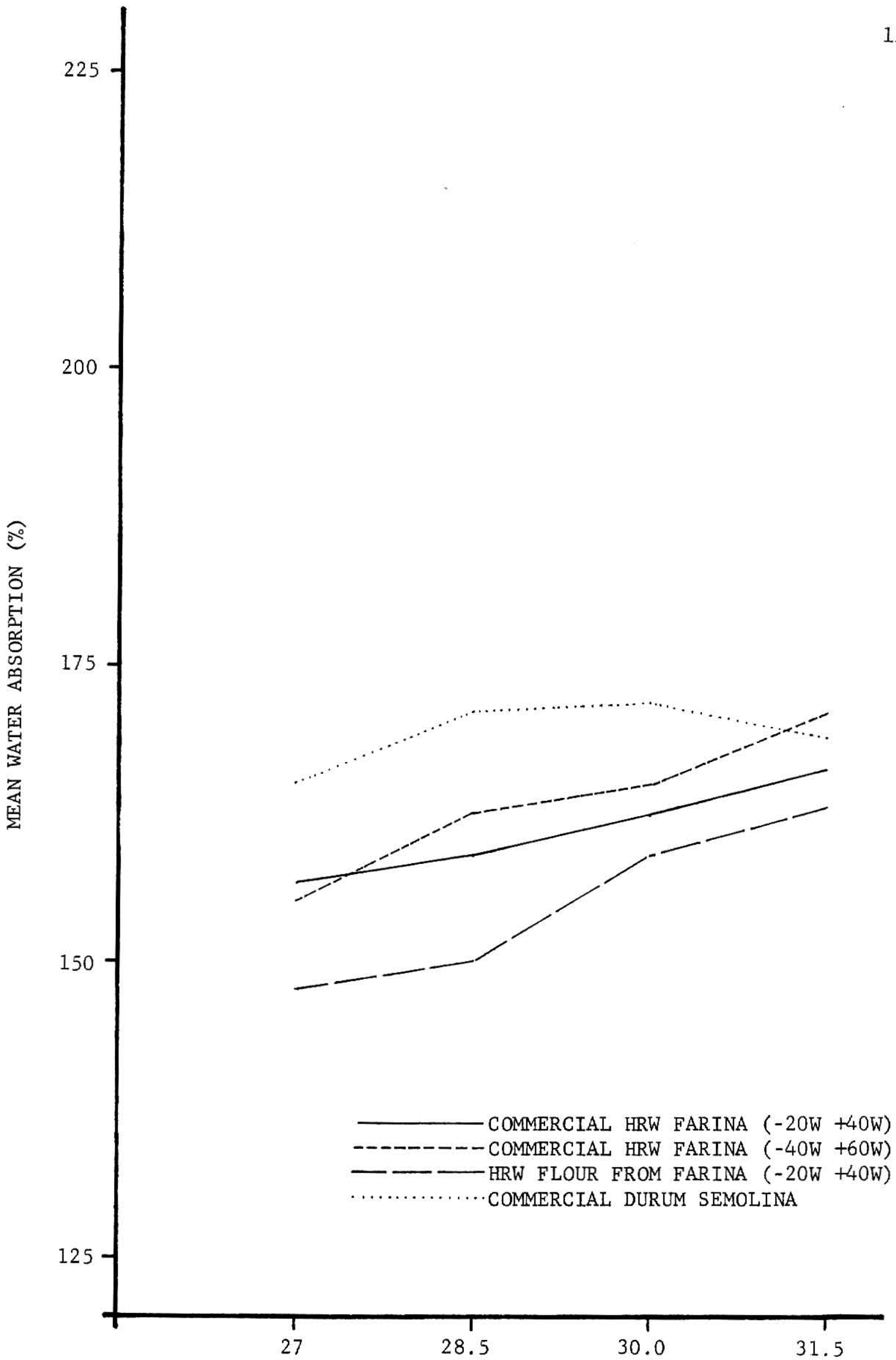

Figure 40. Mean Water Absorption During Cooking of All Spaghetti at Different Absorptions.

The quadratic and cubic components in these trends are not significant. On the other hand, in the case of P4 the trend shows definite curvature and only the quadratic components are significant, accounting for 80% of the sum of squares among original absorption for this product. The significance of the product x original absorption interaction originates from a definitely different trend for water absorption during cooking by original absorption for P4. These results are depicted graphically in Fig. 40.

Firmness of Spaghetti During Cooking

The firmness data of spaghetti after cooking for the four products and four different absorptions is shown in Table XIX. The means over products firmness and time presented in Table XX, XXI, and XXII help understand the nature of the absorption x time, product x time and absorption x product interactions, respectively. The time trends in firmness during cooking with cooking time are illustrated by original water absorptions in Fig. 41 through 44 and by products in Fig. 45 through 48.

The results of the primary analysis of variance for firmness of spaghetti during cooking (data of Table XIX) presented in Table XXIII show that product, original absorption and cooking time have a significant effect on the firmness of spaghetti during cooking, with only the product x absorption (P x A) and product x time (P x T) interactions showing significance at the 5% level.

The overall comparison among products without reference to either original absorption or cooking time (Table XXI) shows significant differences ($P \leq 0.05$) among products with P2 and P4 having the highest and lowest firmness, respectively.

The overall comparison among original absorptions without reference to either product or cooking time (Table XXII) shows that the firmness for

TABLE XIX

Firmness During Cooking

Absorption		5 Min	10 Min	15 Min	20 Min	25 Min	30 Min
27%	Commercial HRW farina (-20W +40W)	173.0	102	57.0	43.5	44.5	36.5
27%	Commercial HRW farina (-20W +40W)	170.0	105	56.5	48.0	43.0	37.5
27%	Commercial HRW farina (-20W +40W)	174.0	101	57.5	47.0	43.5	36.0
27%	Commercial HRW farina (-20W +40W)	177.0	100	53.5	49.5	42.5	36.5
27%	Commercial HRW farina (-20W +40W)	178.0	108	54.5	46.5	44.0	37.0
27%	Commercial HRW farina (-40W +60W)	180.0	98	56.5	50.0	39.0	38.0
27%	Commercial HRW farina (-40W +60W)	176.0	100	57.0	48.5	40.5	37.5
27%	Commercial HRW farina (-40W +60W)	178.0	98	58.0	49.5	41.0	38.0
27%	Commercial HRW farina (-40W +60W)	182.0	102	58.5	48.5	39.5	38.5
27%	Commercial HRW farina (-40W +60W)	180.0	98	59.0	49.0	41.0	38.5
27%	HRW Flour from farina (-20W +40W)	167.0	88	55.5	46.5	43.0	39.5
27%	HRW Flour from farina (-20W +40W)	162.0	88	54.5	47.0	42.5	40.5
27%	HRW Flour from farina (-20W +40W)	164.0	85	53.5	46.0	41.5	38.5
27%	HRW Flour from farina (-20W +40W)	164.0	83	53.0	46.0	43.5	38.5
27%	HRW Flour from farina (-20W +40W)	166.0	86	54.0	45.5	43.5	40.5
27%	Commercial durum semolina	146.0	69	48.0	39.5	38.5	36.5
27%	Commercial durum semolina	150.0	72	48.5	40.5	38.5	35.0
27%	Commercial durum semolina	150.0	69	49.5	40.0	38.0	35.5
27%	Commercial durum semolina	148.0	72	48.0	40.5	38.0	36.0
27%	Commercial durum semolina	146.0	70	47.5	40.0	38.0	36.5

TABLE XIX (Cont.)

Firmness During Cooking

Absorption		5 Min	10 Min	15 Min	20 Min	25 Min	30 Min
28.5%	Commercial HRW farina (-20W +40W)	179.0	100	56.0	44.5	43.0	37.0
28.5%	Commercial HRW farina (-20W +40W)	178.0	99	59.5	46.0	42.0	37.5
28.5%	Commercial HRW farina (-20W +40W)	178.0	102	55.0	44.0	43.0	38.5
28.5%	Commercial HRW farina (-20W +40W)	181.0	106	58.0	47.5	43.5	38.5
28.5%	Commercial HRW farina (-20W +40W)	174.0	101	60.5	43.5	43.5	36.5
28.5%	Commercial HRW farina (-40W +60W)	177.0	101	61.5	47.5	40.0	39.0
28.5%	Commercial HRW farina (-40W +60W)	176.0	98	63.0	49.0	41.0	37.5
28.5%	Commercial HRW farina (-40W +60W)	174.0	99	64.0	49.5	40.0	38.5
28.5%	Commercial HRW farina (-40W +60W)	174.0	103	60.0	48.0	39.0	38.5
28.5%	Commercial HRW farina (-40W +60W)	179.0	100	60.5	46.5	39.5	39.0
28.5%	HRW Flour form farina (-20W +40W)	166.0	90	53.0	44.5	42.5	40.5
28.5%	HRW Flour from farina (-20W +40W)	162.0	88	52.0	44.0	42.5	41.0
28.5%	HRW Flour from farina (-20W +40W)	164.0	89	53.5	44.0	41.5	40.0
28.5%	HRW Flour from farina (-20W +40W)	166.0	88	50.0	45.5	41.5	39.5
28.5%	HRW Flour from farina (-20W +40W)	162.0	89	52.0	43.5	41.0	40.0
28.5%	Commercial durum semolina	143.0	80	50.5	42.5	38.0	35.5
28.5%	Commercial durum semolina	145.0	82	50.0	41.0	37.0	36.5
28.5%	Commercial durum semolina	143.0	80	49.5	41.5	37.0	36.0
28.5%	Commercial durum semolina	144.0	79	51.0	40.5	38.0	36.5
28.5%	Commercial durum semolina	146.0	77	49.0	40.5	37.5	36.5

TABLE XIX (Cont.)

Firmness During Cooking

Absorption		5 Min	10 Min	15 Min	20 Min	25 Min	30 Min
30%	Commercial HRW farina (-20W +40W)	172.0	98	54.5	44.5	38.0	36.0
30%	Commercial HRW farina (-20W +40W)	171.0	97	56.5	44.0	37.5	35.5
30%	Commercial HRW farina (-20W +40W)	170.0	102	55.0	43.0	37.5	36.0
30%	Commercial HRW farina (-20W +40W)	172.0	99	55.0	44.5	38.0	36.5
30%	Commercial HRW farina (-20W +40W)	169.0	98	53.0	45.0	37.0	35.5
30%	Commercial HRW farina (-40W +60W)	178.0	98	58.0	48.0	38.0	37.5
30%	Commercial HRW farina (-40W +60W)	170.0	100	60.5	49.5	39.5	38.0
30%	Commercial HRW farina (-40W +60W)	175.0	98	60.0	47.0	38.5	38.5
30%	Commercial HRW farina (-40W +60W)	172.0	98	58.0	47.0	38.0	38.0
30%	Commercial HRW farina (-40W +60W)	176.0	97	59.0	46.0	38.5	38.0
30%	HRW Flour from farina (-20W +40W)	158.0	78	50.5	44.0	42.0	38.5
30%	HRW Flour from farina (-20W +40W)	156.0	80	49.0	43.5	41.5	39.0
30%	HRW Flour from farina (-20W +40W)	158.0	76	51.5	42.5	42.0	37.5
30%	HRW Flour from farina (-20W +40W)	160.0	80	50.5	43.5	41.5	38.0
30%	HRW Flour from farina (-20W +40W)	162.0	79	50.0	42.5	41.5	37.5
30%	Commercial durum semolina	140.0	74	47.5	40.0	36.0	36.0
30%	Commercial durum semolina	139.0	72	46.5	39.0	37.0	35.0
30%	Commercial durum semolina	137.0	72	45.5	39.5	37.5	35.5
30%	Commercial durum semolina	135.0	72	46.0	38.5	36.0	36.0
30%	Commercial durum semolina	140.0	71	45.0	39.0	37.5	35.0

TABLE XIX (Cont.)

Firmness During Cooking

Absorption		5 Min	10 Min	15 Min	20 Min	25 Min	30 Min
31.5%	Commercial HRW farina (-20W +40W)	166.0	88	51.0	40.0	36.5	35.0
31.5%	Commercial HRW farina (-20W +40W)	168.0	90	49.0	40.5	35.0	34.5
31.5%	Commercial HRW farina (-20W +40W)	161.0	88	50.5	38.0	35.5	34.5
31.5%	Commercial HRW farina (-20W +40W)	163.0	91	48.0	39.5	36.5	35.0
31.5%	Commercial HRW farina (-20W +40W)	164.0	93	46.5	39.5	34.5	34.5
31.5%	Commercial HRW farina (-40W +60W)	173.0	95	57.5	44.5	42.0	37.0
31.5%	Commercial HRW farina (-40W +60W)	171.0	96	56.0	46.0	42.0	37.5
31.5%	Commercial HRW farina (-40W +60W)	174.0	94	56.0	43.0	41.5	39.0
31.5%	Commercial HRW farina (-40W +60W)	168.0	93	57.0	42.5	41.5	38.5
31.5%	Commercial HRW farina (-40W +60W)	173.0	93	54.0	45.5	42.5	37.0
31.5%	HRW Flour from farina (-20W +40W)	160.0	82	46.0	39.5	36.0	32.5
31.5%	HRW Flour from farina (-20W +40W)	156.0	83	47.5	37.0	35.5	32.0
31.5%	HRW Flour from farina (-20W +40W)	156.0	84	46.0	38.5	35.0	32.0
31.5%	HRW Flour from farina (-20W +40W)	154.0	81	46.5	37.5	35.5	31.0
31.5%	HRW Flour from farina (-20W +40W)	156.0	80	47.0	38.0	35.5	32.0
31.5%	Commercial durum semolina	144.0	70	45.0	36.0	35.5	33.5
31.5%	Commercial durum semolina	140.0	68	46.0	36.5	36.0	34.0
31.5%	Commercial durum semolina	138.0	69	44.0	37.5	35.5	34.5
31.5%	Commercial durum semolina	142.0	68	45.0	35.0	36.5	34.5
31.5%	Commercial durum semolina	144.0	67	45.5	37.0	35.5	34.0

TABLE XX

Firmness of Spaghetti During Cooking by Original Absorption and Cooking Time (A X T Interaction)

	Time (min)						
Absorption	5	10	15	20	25	30	$\overline{X}$
27.0%	166.55	89.70	54.575	45.575	41.175	37.55	72.425000 A
28.5%	165.55	92.55	55.425	44.675	40.55	38.05	72.800000 A
30.0%	160.50	86.95	52.575	43.525	38.65	36.875	69.845833 B
31.5%	158.55	83.65	49.20	39.575	37.20	34.625	67.133333 C

Means with the same letter are not significantly different.

Alpha level = 0.05 DF = 45 MS error = 3.39505

TABLE XXI

Firmness of Spaghetti During Cooking By Product and Cooking Time (P X T Interaction)

Product	Time (min) 5	10	15	20	25	30	Mean	Grouping
P1	171.900	98.400	54.35	43.925	39.925	36.150	74.108333	A
P2	175.300	97.950	58.700	47.250	40.125	38.100	76.2375	B
P3	160.95	83.85	50.775	42.950	40.450	37.425	69.400	C
P4	143.000	72.650	47.375	39.375	37.075	35.425	62.458333	D

Mean with the same letter are not significantly different.

Alpha level = 0.05 DF = 45 MS error = 3.39505

TABLE XXII

Firmness of Spaghetti During *Cooking* By Products and Original

Absorptions (P X A Interaction)

	P1	P2	P3	P4	Mean	Grouping
A_1	76.750	77.2666667	72.20000	63.4833333	72.425	A
A_2	77.1333333	77.4166667	71.8666667	64.7833333	72.800	A
A_3	73.6833333	75.9166667	68.4500000	61.3333333	69.845833	B
A_4	68.8666667	74.3500000	65.0833333	60.2333333	67.133333	C

Means with the same letter are not significantly different.

Alpha level = 0.05 DF = 45 MS error = 3.39505

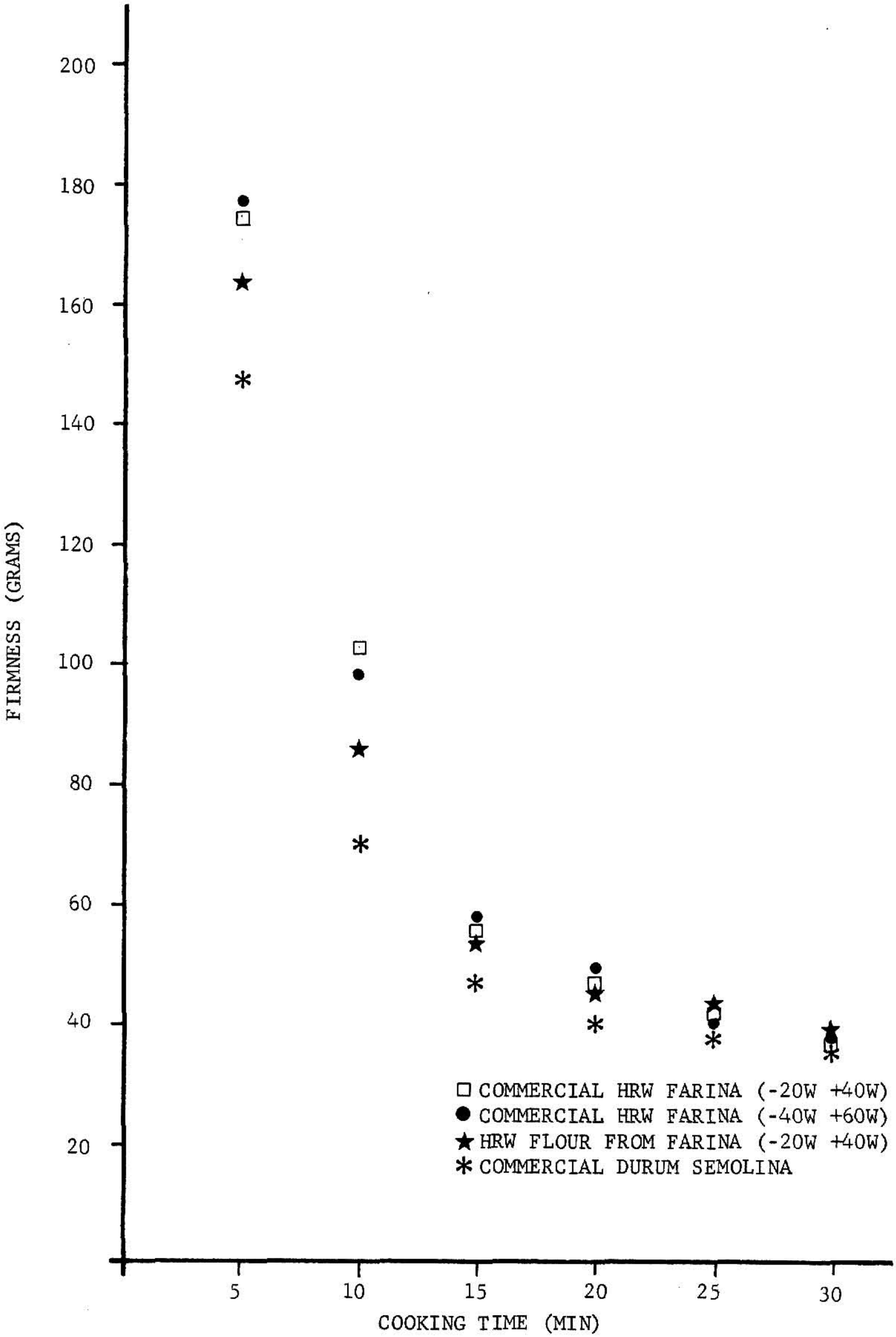

Figure 41. Firmness During Cooking for the 27% Original Water Absorption Spaghetti .

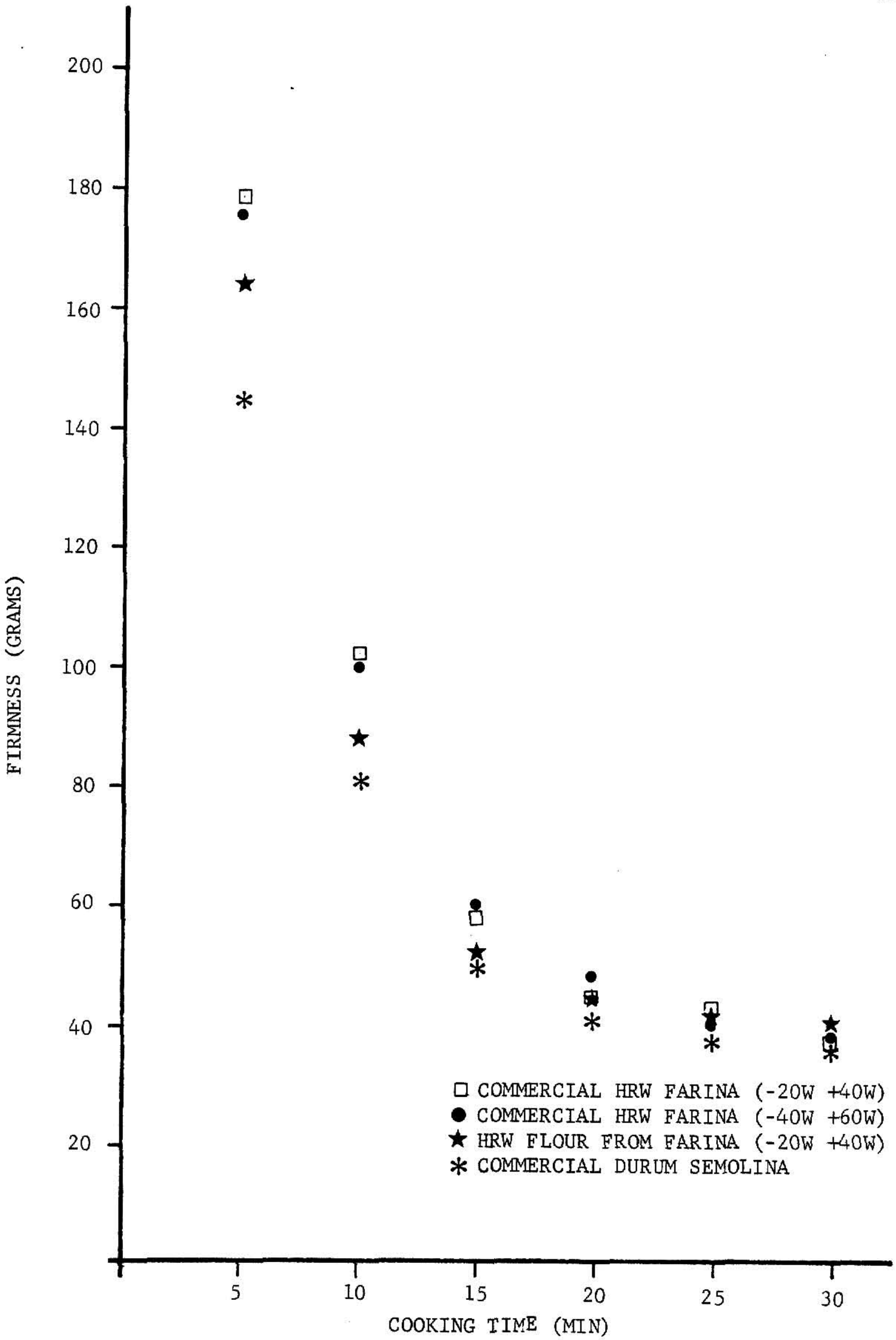

Figure 42. Firmness During Cooking for the 28.5% Original Water Absorption Spaghetti .

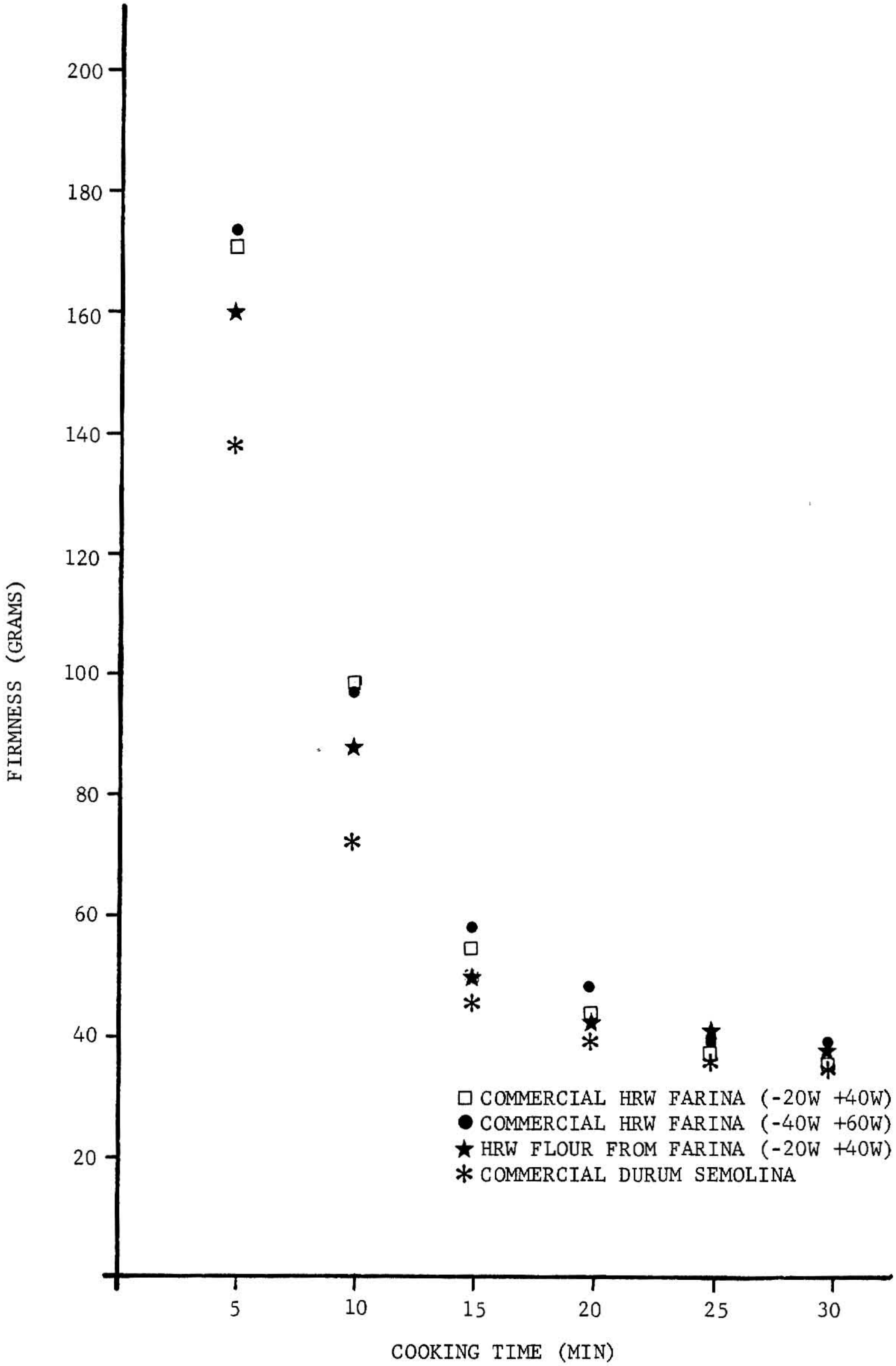

Figure 43. Firmness During Cooking for the 30.0% Original Water Absorption Spaghetti .

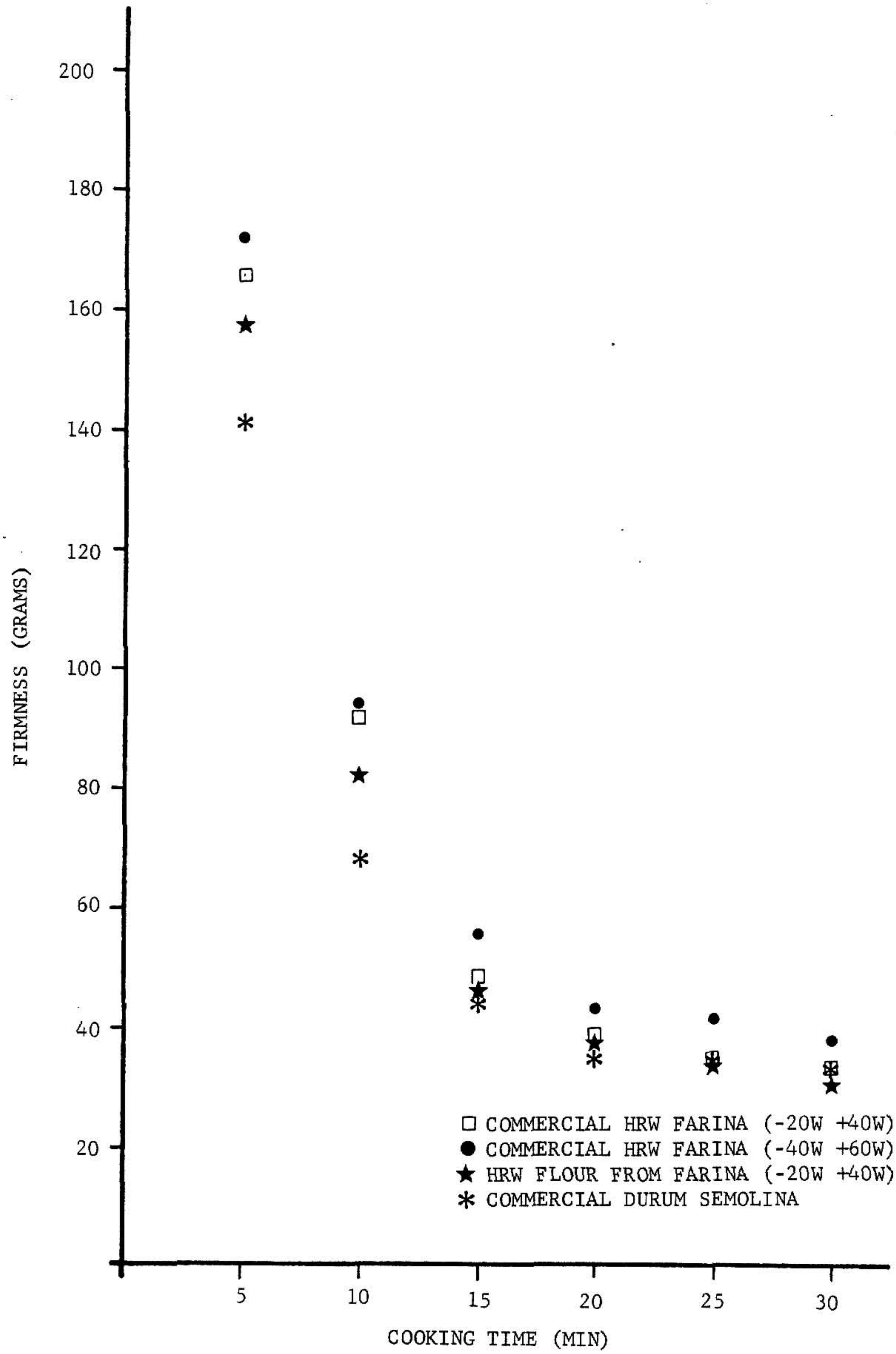

Figure 44. Firmness During Cooking for the 31.5% Original Water Absorption Spaghetti .

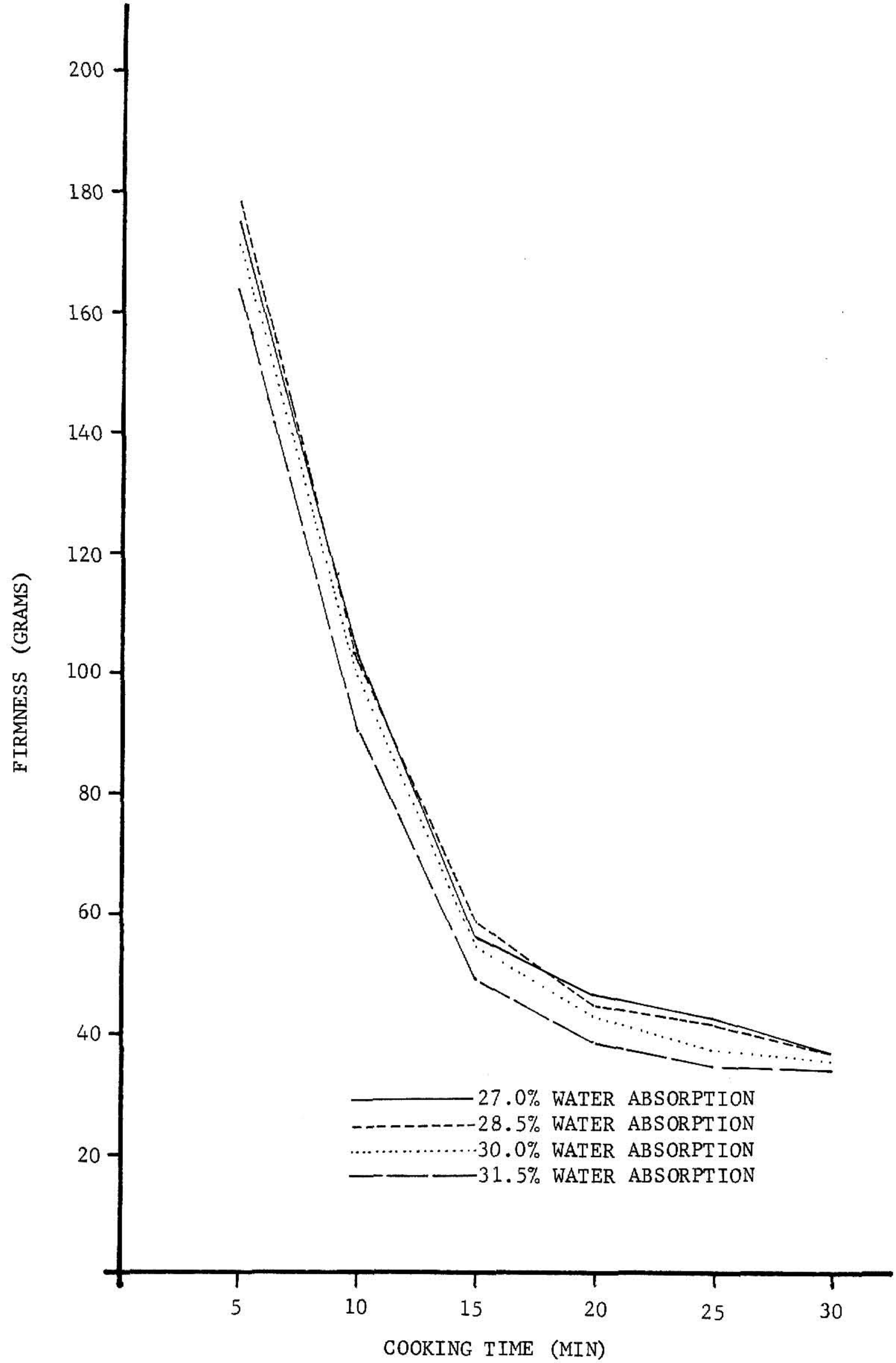

Figure 45. Effect of Original Water Absorption on Firmness During Cooking for Commercial HRW Farina (-20W +40W).

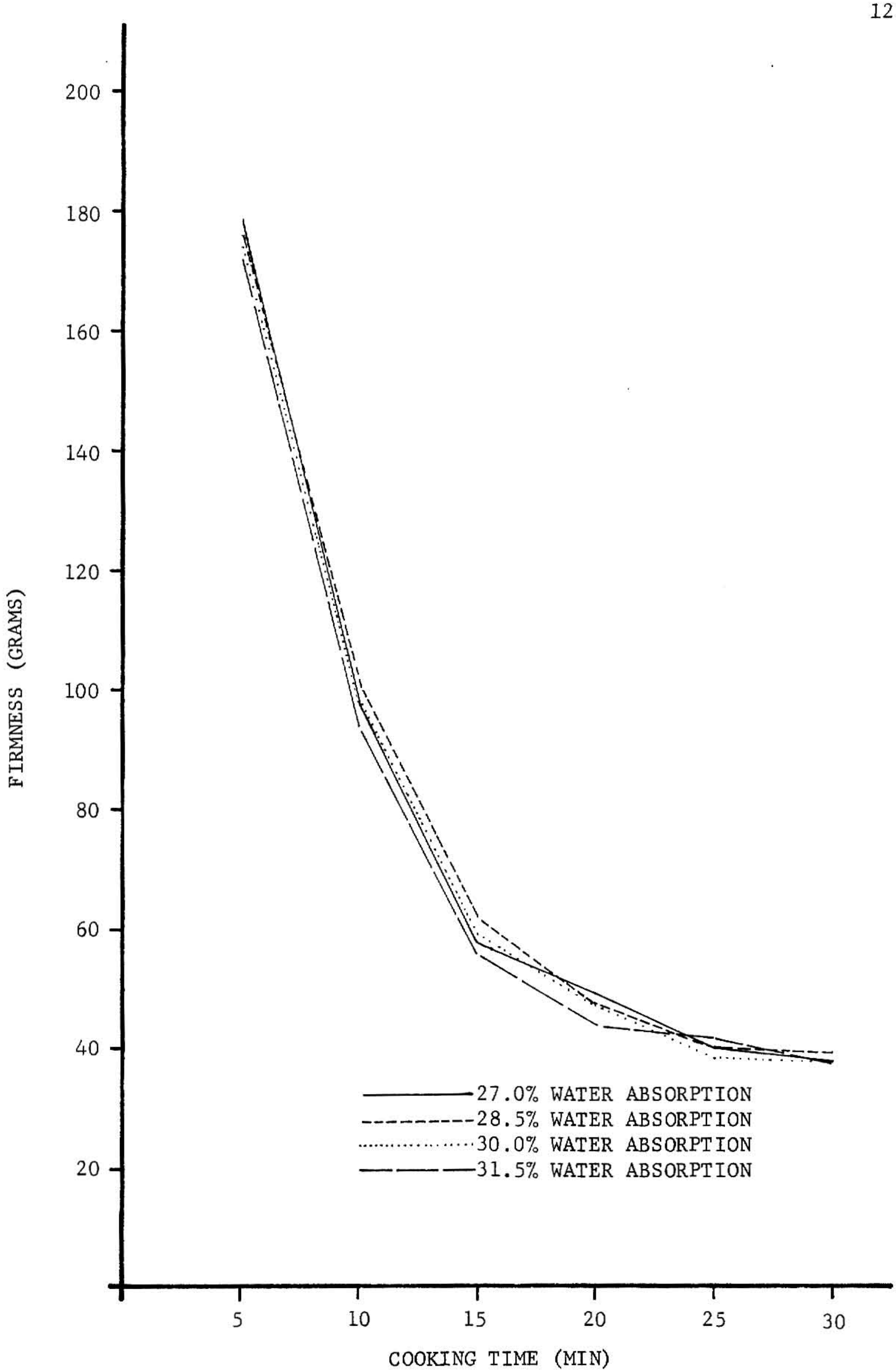

Figure 46. Effect of Original Water Absorption on Firmness During Cooking for Commercial HRW Farina (-40W +60W).

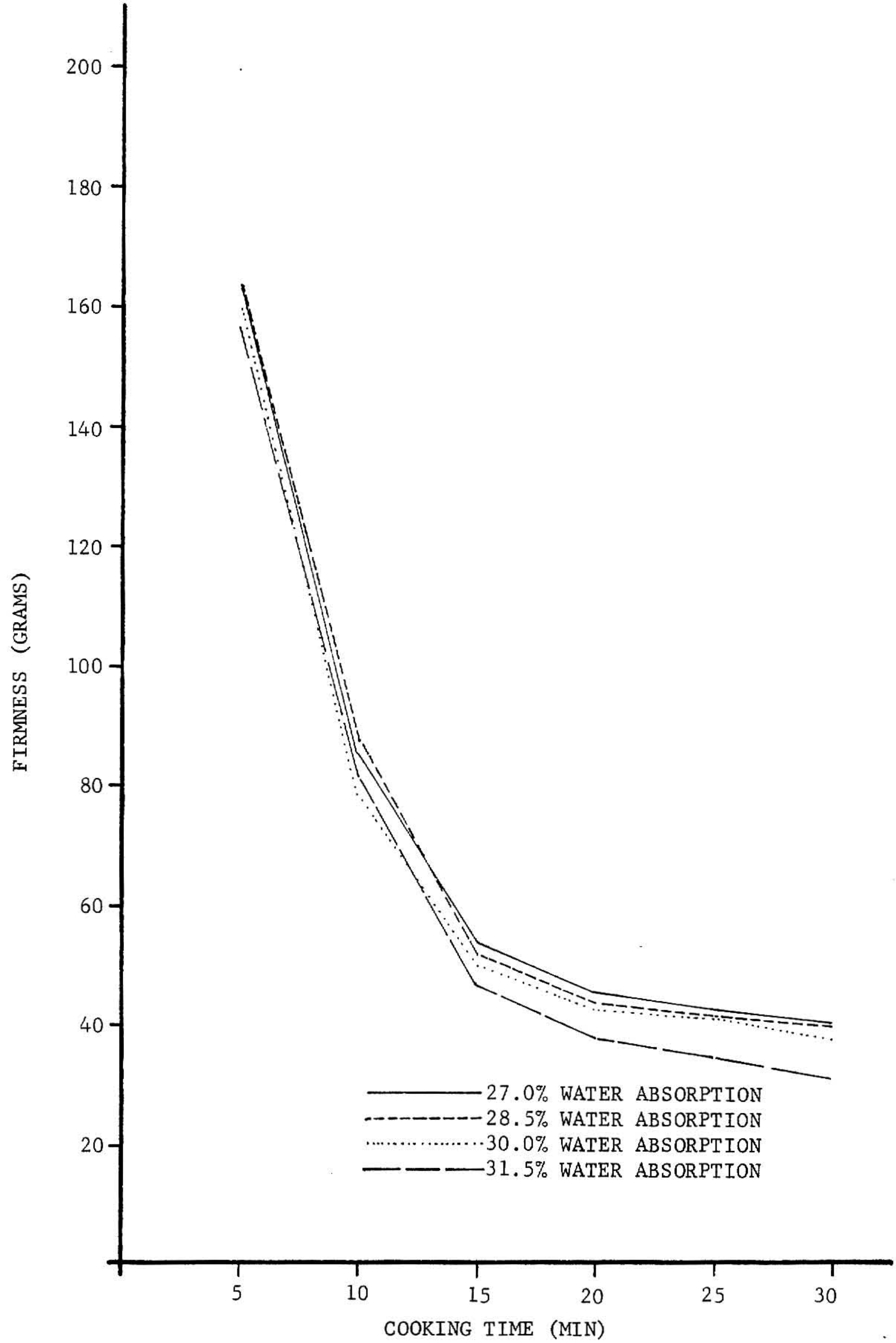

Figure 47. Effect of Original Water Absorption on Firmness During Cooking for HRW Flour From Farina (-20W +40W).

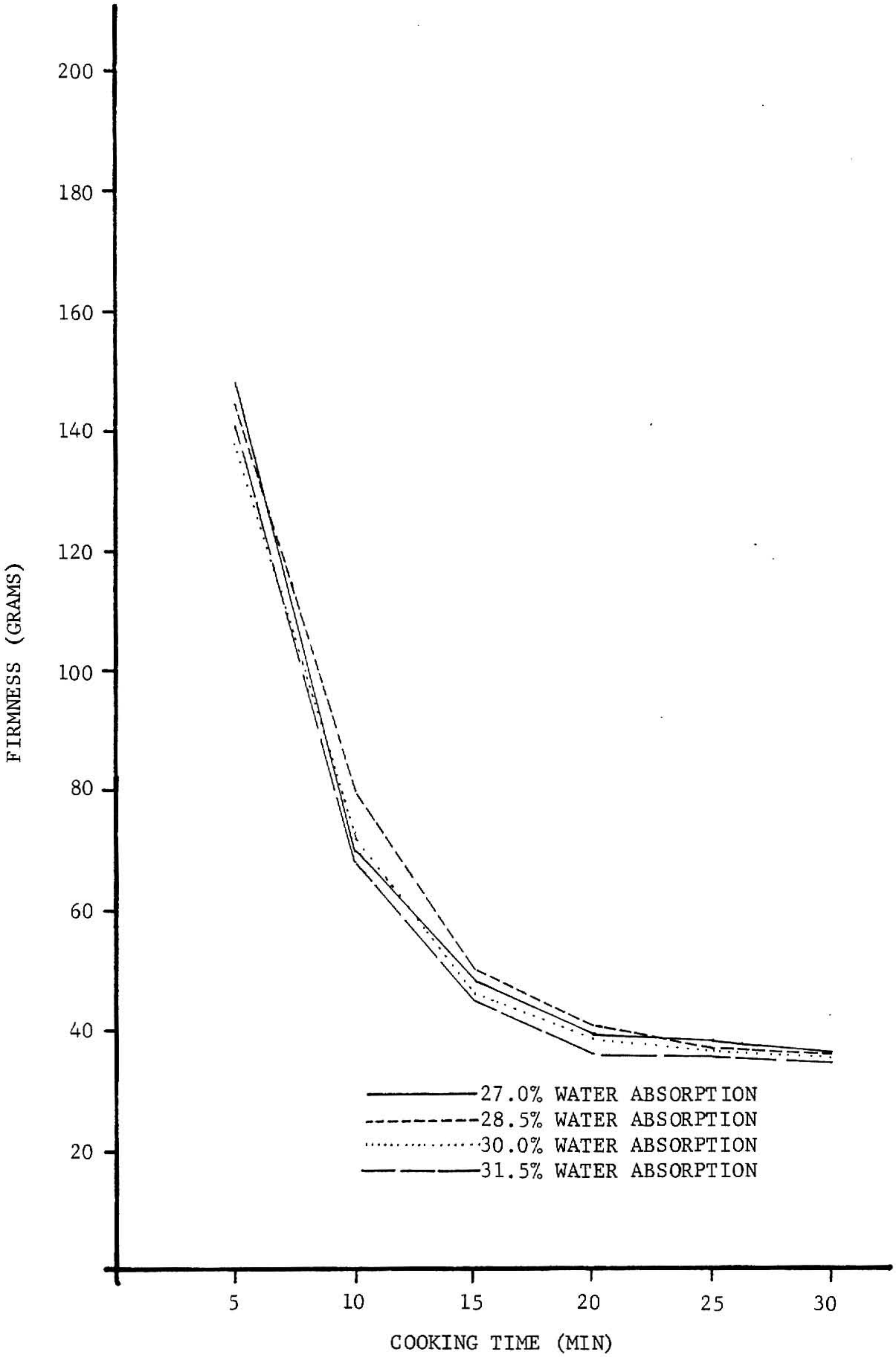

Figure 48. Effect of Original Water Absorption on Firmness During Cooking for Commercial Durum Semolina.

TABLE XXIII

Primary Analysis of Variance for Firmness of Spaghetti During Cooking

Comparison of Four Products and Four Original Absorptions in Dough Preparations

Source	DF	MS	F Value	Pr > F
Product (P)	3	894.9557	263.46	0.0001
Absorption (A)	3	165.9807	48.89	0.0001
Time (T)	5	38357.6496	11298.11	0.0001
T linear	1	141203.7772	41591.09	0.0001
T quadratic	1	44926.0939	13232.83	0.0001
T cubic	1	5576.9650	1642.68	0.0001
Remainder	2	40.7060	11.99	
P X A	9	8.6951	2.56	0.0180
P X T	15	145.6445	42.31	0.0001
P X T linear	3	610.7981	179.91	0.0001
Remainder	12	26.8561	7.91	
A X T	15	6.1308	1.81	0.0640
A X T linear	3	19.0234	5.60	0.0024
Remainder	12	2.9077	0.86	
Error	45	3.3950		

TABLE XXIV

Duncan's Multiple Range Test for Variable

Firmness During Cooking

Grouping	Mean	Product	Absorption
A	77.4167	2	28.5
A	77.2667	2	27.0
A	77.1333	1	28.5
A	76.7500	1	27.0
B A	75.9167	2	30.0
B C	74.3500	2	31.5
D C	73.6833	1	30.0
D	72.2000	3	27.0
D	71.8667	3	28.5
E	68.8667	1	31.5
E	68.4500	3	30.0
F	65.0833	3	31.5
F	64.7833	4	28.5
F	63.4833	4	27.0
G	61.3333	4	30.0
G	60.2333	4	31.5

Means with the same letter are not significantly different.

Alpha level = 0.10   DF = 45   MS error = 3.39505

TABLE XXV

Analysis of Variance for the Mean Firmness of Spaghetti During Cooking (P X T Interaction)

Product	Time	Mean Firmness	Mean square	Slope
P1	5	171.900	L 42,716.1806	-4.94
P1	10	98.400		
P1	15	54.350	Q 12,328.7086	
P1	20	43.925		
P1	25	39.925	C 1,152.4150	
P1	30	36.150		
P2	5	175.300	L 43,343.4489	-4.98
P2	10	97.950		
P2	15	58.700	Q 12,150.0603	
P2	20	47.250		
P2	25	40.125	C 1,231.6651	
P2	30	38.100		
P3	5	160.950	L 32,628.9670	-4.32
P3	10	83.850		
P3	15	50.775	Q 11,558.5074	
P3	20	42.950		
P3	25	40.450	C 1,773.7861	
P3	30	37.425		
P4	5	143.000	L 24,347.5750	-3.73
P4	10	72.650		
P4	15	47.375	Q 9,052.1905	
P4	20	39.225		
P4	25	37.075	C 2,215.5125	
P4	30	35.425		

TABLE XXVI

Analysis of Variance for the Mean Firmness of Spaghetti (P X A Interaction)

Product	Absorption	Mean water absorption	Mean square	Slope
P1	27.0	76.7500	L 220.3214	-1.81
P1	28.5	77.1333	Q 40.5584	
P1	30.0	73.6833	C 1.8245	
P1	31.5	68.8667		
P2	27.0	77.2667	L 31.5194	-0.68
P2	28.5	77.4167	Q 4.4606	
P2	30.0	75.9167	C 0.7521	
P2	31.5	74.3500		
P3	27.0	72.2000	L 184.0183	-1.65
P3	28.5	71.8667	Q 13.8023	
P3	30.0	68.4500	C 2.9455	
P3	31.5	65.0833		
P4	27.0	63.4833	L 52.2720	-0.88
P4	38.5	64.7833	Q 8.6400	
P4	30.0	61.3333	C 15.1230	
P4	31.5	60.2333		

the 27% and 28.5% original absorptions do not differ statistically and were the highest firmness values. However, these two higher values differ statistically in terms of firmness with the corresponding observed values for the 30% and 31.5% original water absorptions, respectively.

The significant P x A interaction arises because of the different magnitude of differences in firmness of products in the four original water absorption levels, as can be seen in Table XXII. Thus, at the 27% original absorption level, P2 is higher and P4 lower in firmness during cooking, while P1 and P2 are not statistically different, and P3 is statistically different from the other three products. The same ranking of products holds at 28.5%, 30.0% and 31.5%; however, at these original water absorption levels, all the products differ statistically in terms of firmness during cooking.

Comparison among products (Table XXI) shows that the firmness for all the products decreased with cooking time, but, as illustrated in Fig. 49, this occurred at different rates and different levels, thus the significant product x time (P x T) interaction. In general, the higher rates of firmness during cooking corresponded to P2 and P1 and the lowest corresponded to P4; P3 was intermediate. In other words, the time trends of firmness during cooking for the four products considered are not parallel. The range in firmness during cooking after 5 minutes was 32.30 grams (175.3 P2 - 143.0 P4), while the range after 30 minutes of cooking was 2.675 grams (38.1 P2 - 35.425 P4), approximately twelve (12) times the initial value.

Finally the results of a Duncan's Multiple Range test for the 16 product-original water absorption combinations are presented in Table XXIV. The means identified in this table with the same letter do not differ statistically in firmness during cooking, and thus the table results provide a means for selecting equivalent product-original absorption combinations in terms of firmness during cooking.

Similarly, further insight into the nature of the product x time interaction in terms of firmness can be gained through the analysis presented in Table XXV. In this case all the trends in firmness during cooking have a predominant linear component in the range of 70% and a smaller quadratic component in the range of 20%, which nevertheless shows significant curvature in the trends. The trends also occur with different rates of change (slopes) ranging from -4.98 g per minute for P2 to a low -3.73 g per minute for P4. P1 has a very similar rate of change (4.94 g per minute) to that of P2, while P3 with a slope of -4.32 g per minute is intermediate having the observed range in rate of change for the four products. These results are illustrated in Fig. 49.

Further insight into the nature of the product by original absorption interaction can be gained through the analysis of variance of the mean firmness of spaghetti presented in Table XXVI. In this case, once more the general trend of firmness during cooking is examined by products and its original water absorptions in terms of linear, quadratic and cubic components. In this case, there is evidence that as original water absorption increases, the firmness of spaghetti in several decreases linearly. However, from 27% to 28.5% original water absorption levels, a small increase in firmness is observed for products P1, P2, and P4, but not for P3. Above 28.5% original water absorption levels, the firmness for the four products decreases. This accounts for the small quadratic component observed which accounts for 15.44% or less of the sum of squares. In general, however, the decreasing trend in firmness of the products is a linear, accounting for over 83% of the sum of squares due to original water

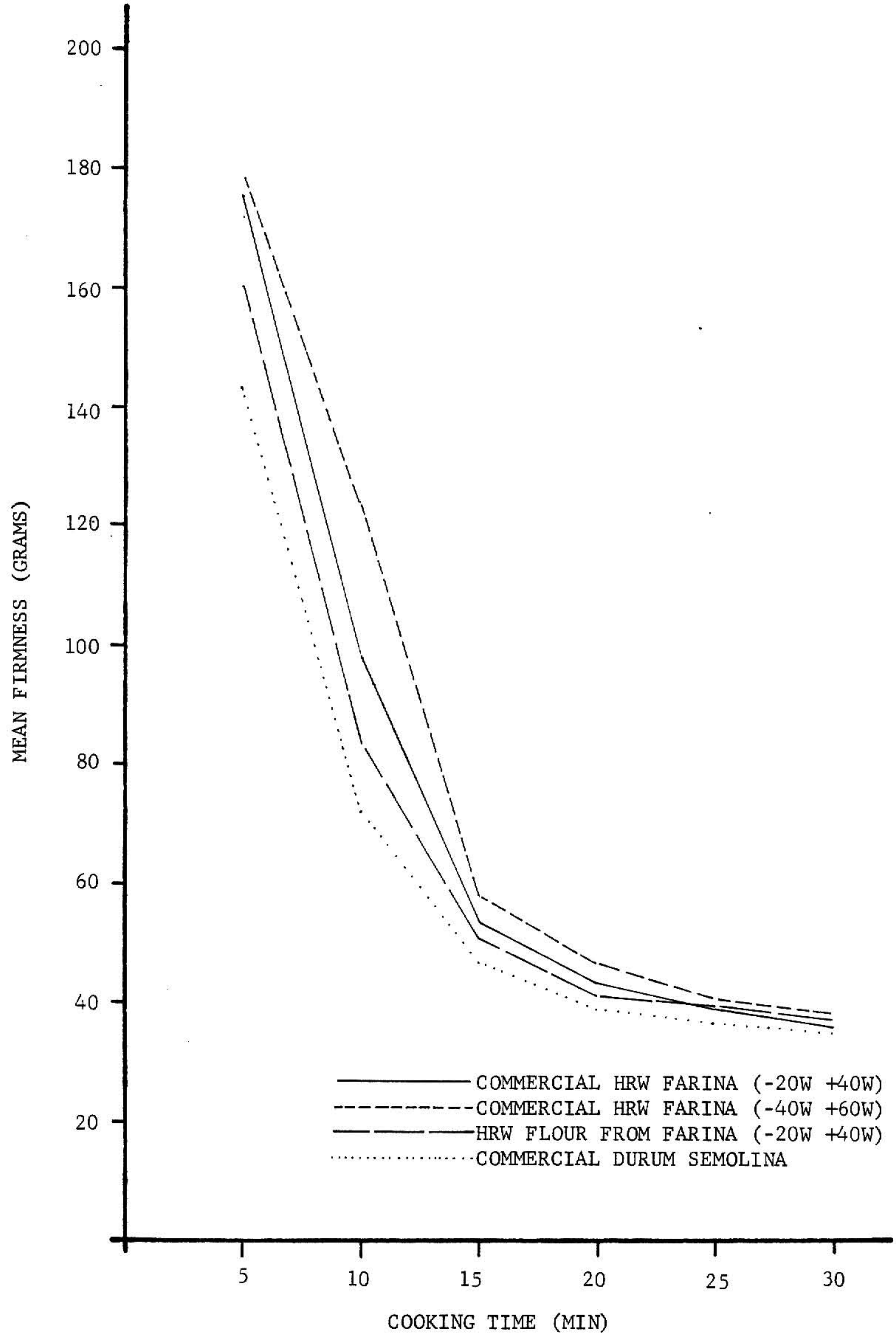

Figure 49. Mean Firmness During Cooking of All Original Water Absorptions for Each Product.

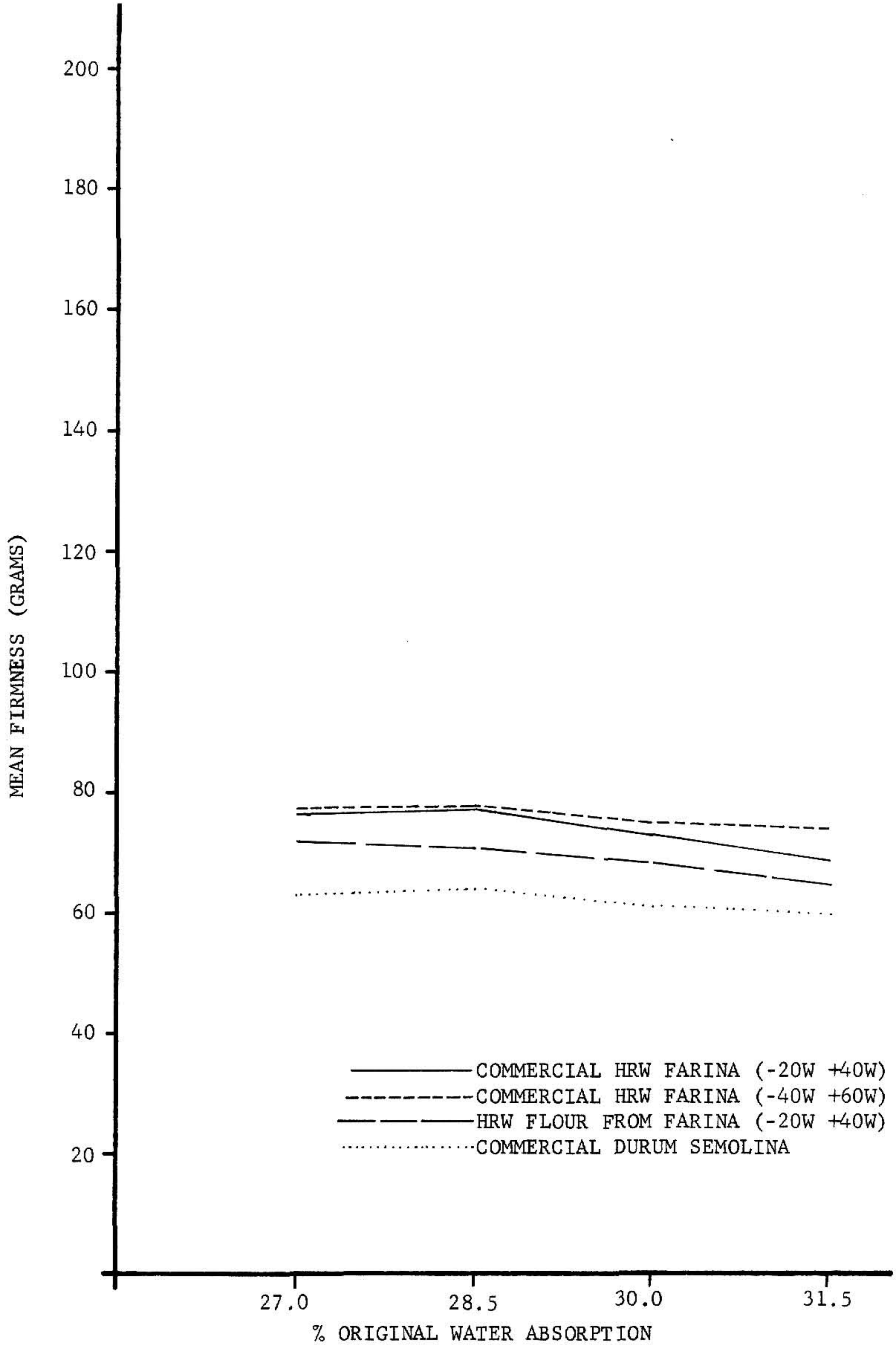

Figure 50. Mean Firmness During Cooking of All Spaghetti at Different Absorptions.

absorption for products P1, P2 and P3. In the case of P4, the linear trend is only 68% linear, 11% quadratic and the remainder (19) is cubic trend. These results are depicted graphically in Fig. 50.

Coloring Additive for Spaghetti

Color is a vital constituent of food. It is one of the first characteristics perceived by the senses and it is indispensable to the consumer as a means for the identification and acceptance of food. Almost all foods have an associated color acceptable to the consumer on the basis of social, geographic, ethnic and historical backgrounds. The color of pastas is quite precise, and manufacturers of pasta products always attempt to have the characteristic yellow color of pasta.

From a modern food-manufacturing viewpoint, color additives are indispensable. Dyes are employed to create new food products and to modify the color of established food products that show color shifts as the result of manufacture and storage.

Colors are employed in dough products, cookies, sandwich fillings, icings and coatings. Ice cream cones at one time were colored with water soluble annatto; however, in recent years there has been a switch to the use of certified colors which are less expensive and offer greater variety of shades. Cone color blends generally contain FD&C Yellow No. 5 and FD&C Yellow No. 6 (57).

In this experiment three different amounts of FD&C Yellow No. 5 were used for matching the natural yellow color of durum wheat spaghetti, when Hard Red Winter wheat was used. The amounts were 4.44 ppm, 8.88 ppm and 13.33 ppm. The 8.88 ppm concentration gave the best result for matching the yellow color of durum semolina made spaghetti using any granulation of Hard Red Winter wheat (see Fig. 51).

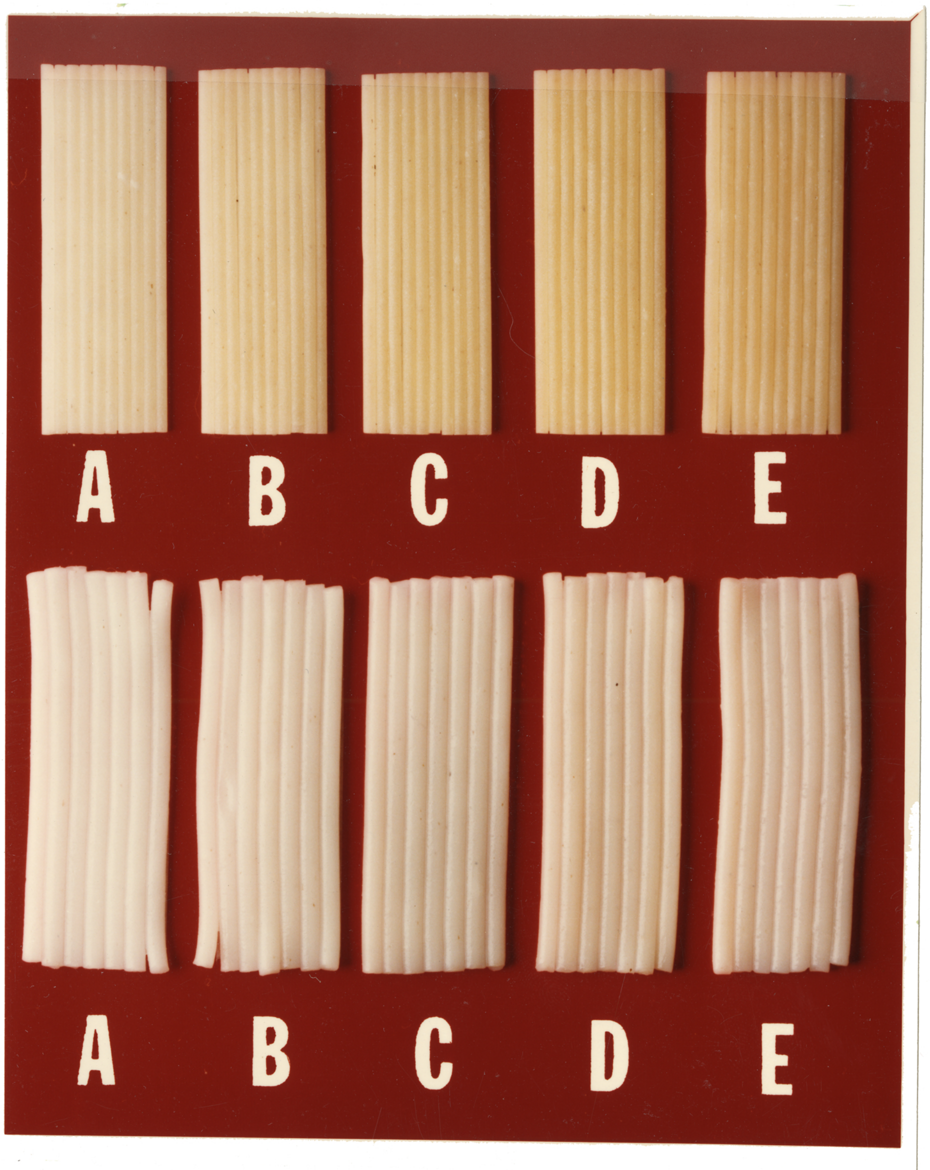

Figure 51. Top Row: Raw Product
Bottom Row: Cooked Product
A. Commercial HRW Farina (-20W+40W)
B. Commercial HRW Farina (-20W+40W) Plus 4.44 PPM FD&C Yellow No. 5
C. Commercial HRW Farina (-20W+40W) Plus 8.88 PPM FD&C Yellow No. 5
D. Commercial HRW Farina (-20W+40W) Plus 13.33 PPM FD&C Yellow No. 5
E. Commercial Durum Semolina

If we compare the above concentration of FD&C Yellow No. 5, with other products that have in their formula FD&C Yellow No. 5, it is practically nothing. Assuming that a person can ingest 100 grams of pasta per day (100 g of pasta before cooking), this means that the person is ingesting 0.8 mg of FD&C Yellow No. 5 during one meal.

The FAO/WHO Expert Committee on Food Additives has as an acceptable daily intake for FD&C Yellow No. 5, 0-7.5 mg/Kg; that is for a 70Kg man, an acceptable daily intake of 525 mg. However, as a "Good Manufacturing Practice," FAO/WHO Expert Committee on Food Additives suggests 16.3 mg/ capita/day.

There are countries like Brazil, Colombia, Bolivia, Peru, and others, where they are price-controlled and their government does not allow the introduction of durum wheat. As a result pastas are made from farina or flour of hard wheat and they are dyed with additives such as FD&C Yellow No. 5 and/or eggs to obtain a pasta product with yellow color. On the other hand, countries like Italy and France, it is my understanding, have laws that require that pasta products be made only from durum wheat.

Here in the U.S. durum wheat is the preferred raw material for making pasta, but in the market there are some pasta products that are made from hard wheat and they are gaining popularity because of their lower price. The acceptability could be more rapid if these pastas were colored to match the yellow color of durum wheat pastas. However, in the U.S. coloring additives are not permitted in pasta products, even if the artificial coloring meets current FDA requirements. Pasta color is important in terms of consumer appeal since consumers consider yellowness an important quality parameter.

CONCLUSIONS

Spaghetti cooking loss and cooking weight values were similar among products, and generally were satisfactory or better than durum semolina used as a control. The spaghetti firmness score appeared satisfactory for the four products with HRW products showing a mean firmness higher than the durum semolina control.

Based on the data obtained, it appears that HRW wheats can be used as a granular source for pasta production. Also, the flour form gave good products, and the appearance is much better for flour than it is for commercial HRW farina (-20W +40W) since some large specks are not visible with the flour form.

The use of a coloring material is very important to increase the market of hard wheats in the U.S. pasta market, because of the tradition that if pasta products are yellow, they are a superior product. This is a very hard task to debate here in the U.S., but the beginning could be in underdeveloped countries, where the price of food is important to the consumer due to low wages and the need for food to feed the world. Underdeveloped countries are in a constant need of products that can be stored for some period of time at a minimum cost, and pasta is one of the products that can satisfy this need. "They are easy to prepare and can be stored for long periods of time with no deterioration." Furthermore, durum wheats command a premium over common wheats in the world market, and this factor, together with foreign-exchange problems, can give the lead to widespread use of hard wheats in underdeveloped countries, where the majority of the world's population lives.

For the future, pastas are one of the forms for storing food at a minimum cost, since if they are dried, they can be stored for relatively long periods of time without undergoing appreciable deterioration.

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COMPARISON OF THE SPAGHETTI MADE FROM HARD RED WINTER WHEAT FARINA, HARD RED WINTER WHEAT FLOUR AND DURUM WHEAT SEMOLINA

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ABSTRACT

The use of wheat in the form of pasta products is widespread in today's world and its consumption has been on a rising trend over the years. This is because pasta products are easy to prepare and after they are dried, they can be conveniently stored for relatively long periods of time with little or no deterioration.

Pasta products can be processed from any type of wheat. However, here in the U.S. durum wheat is the preferred raw material, because its yellow color is important in terms of consumer appeal since the consumer considers yellowness an important quality parameter.

Due to price and foreign-exchange problems in many European and South American countries, the use of hard wheats for pasta manufacturing is a common practice.

At present there are pasta manufacturers making their pasta products from semolina, farina and flour. It is known that the uniformity of the particles is very important. But there is limited data available on the subject of granulation of the raw product over the cooking of the pasta. For this purpose pasta has been made from commercial HRW farina (-20W +40W), commercial HRW farina (-40W +60W), HRW flour from farina (-20W +40W) and commercial durum semolina as a control. The water absorption during cooking, the resistance to disintegration and firmness of the cooked spaghetti products of the above raw materials have been compared.