INVESTIGATIONS ABOUT THE POSSIBILITY TO MEASURE QUALITY CHARACTERISTICS OF COOKED POTATOES BY INSTRUMENTAL METHODS

CENTRALE LANDBOUWCATALOGUS
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Dit proefschrift met stellingen van

PIETER ANNE SCHIPPERS,

landbouwkundig ingenieur,
geboren te Borne, 5 september 1924,
is goedgekeurd door de promotor,

DR. C. DEN HARTOG,

hoogleraar in de leer van de voeding
en de voedselbereiding.

De Rector Magnificus
der Landbouwhogeschool

W. F. EIJSVOOGEL

Wageningen, 5 november 1962.

NN 8201, 338

INVESTIGATIONS ABOUT THE POSSIBILITY TO MEASURE QUALITY CHARACTERISTICS OF COOKED POTATOES BY INSTRUMENTAL METHODS

(Met een samenvatting in het Nederlands)

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD
VAN DOCTOR IN DE LANDBOUWKUNDE
OP GEZAG VAN DE RECTOR MAGNIFICUS, IR. W. F. EIJSVOOGEL,
HOOGLERAAR IN DE HYDRAULICA, DE BEVLOEIING,
DE WEG- EN WATERBOUWKUNDE EN DE BOSBOUWARCHITECTUUR,
TE VERDEDIGEN TEGEN DE BEDENKINGEN
VAN EEN COMMISSIE UIT DE SENAAT
DER LANDBOUWHOGESCHOOL TE WAGENINGEN
OP WOENSDAG 12 DECEMBER 1962
TE 16 UUR

DOOR

P. A. SCHIPPERS

J. B. WOLTERS GRONINGEN 1962

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I

Houdbaarheidsverschillen bij aardappelen, voor zover tot uiting komend in verschillen in aantasting door Fusarium coeruleum in het voorjaar, worden, indien men rassen vergelijkt, voornamelijk veroorzaakt door een uiteenlopende vatbaarheid van deze rassen, maar bij vergelijking van partijen van een zelfde ras moet de variatie in besmettingsgraad van deze partijen als de voornaamste oorzaak worden gezien.

P. A. Schippers, *Dry rot of the potato; preliminary publication.*
European Potato Journal 5 (1962) 132–146.

II

In de practijk kunnen teleurstellingen tengevolge van een slechte houdbaarheid van voor Fusarium coeruleum vatbare rassen in belangrijke mate worden verminderd door gepaste maatregelen te nemen op grond van de graad van besmetting met Fusarium coeruleum van de partijen.

P. A. Schippers, Dry rot of the potato; preliminary publication.
European Potato Journal 5 (1962) 132–146.

III

Hoewel de bemesting, in afwijking van de veelal gehuldigde opvatting, wel degelijk een duidelijke invloed op de kwaliteitseigenschappen van gekookte aardappelen kan uitoefenen, zijn de resultaten dermate afhankelijk van andere, ten dele onbekende, factoren, dat een verdere kwaliteitsverbetering door middel van bemestingsmaatregelen niet is te bereiken.

P. A. Schippers, The influence of nitrogen and potassium fertilization on the cooking quality of potatoes.
European Potato Journal 4 (1961) 224–242.

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Aan de nagedachtenis van DR. IR. W. H. DE JONG (1895–1962)

VOORWOORD

Kort na het gereed komen van dit proefschrift bereikte mij de ontstellende tijding van het overlijden van DR. IR. W. H. DE JONG, vóór zijn pensionnering in 1960 directeur van het Instituut voor Bewaring en Verwerking van Landbouwproducten te Wageningen. Mijn dank voor de grote invloed die hij heeft gehad op mijn wetenschappelijke vorming en voor de belangstelling die hij steeds zowel voor mijn persoonlijke omstandigheden als voor mijn werk toonde, meen ik het beste tot uitdrukking te brengen door dit proefschrift aan zijn nagedachtenis op te dragen.

Grote dank ben ik verschuldigd aan PROFESSOR DR. C. DEN HARTOG niet alleen vanwege het feit dat hij bereid was op te treden als promotor op een terrein vol voetangels en klemmen, maar ook voor de zeer grote mate van vrijheid die hij me bij mijn onderzoek liet. Zijn interesse in en critiek op dit werk waren bizonder stimulerend.

Niet minder groot is mijn dank aan de directeur, IR. P. WIERTSEMA, en het bestuur van het Instituut voor Bewaring en Verwerking van Landbouwproducten, zowel voor hun goedkeuring de resultaten van dit voor bovengenoemd instituut uitgevoerde onderzoek te publiceren in de vorm van een proefschrift, als voor het feit dat zij mij zo lang en ongestoord in Assen mijn gang lieten gaan. Deze dank strekt zich tevens uit tot het bestuur en de Werkcommissie Aardappelen van het Provinciaal Onderzoekcentrum voor de Landbouw in Drenthe voor de gelegenheid, mij geboden, een deel van mijn aan het Onderzoekcentrum toekomende tijd te besteden aan dit onderzoek. Van de vrijheid die zij allen mij bij dit werk lieten meen ik nuttig gebruik gemaakt te hebben, hetgeen, naar ik hoop, in de resultaten tot uitdrukking komt.

Op deze plaats wil ik tevens een woord van bizondere waardering uiten voor de steun die ik bij de eerste schreden op dit terrein ondervond van directeur en medewerkers van het Proefstation voor Aardappelverwerking te Groningen. DR. J. HOFSTEE ben ik bizonder erkentelijk voor zijn bereidwilligheid mij en mijn medewerkers gelegenheid te geven op zijn Proefstation te werken; DR. A. H. A. DE WILLIGEN ben ik zeer dankbaar voor de wijze waarop hij steeds zijn grote kennis van de chemie van de aardappel te mijner beschikking stelde, alsmede voor de wijze waarop hij mij ook bij de uitvoering van het onderzoek steunde; de overige medewerkers komt een woord van dank toe voor de soepelheid waarmee hun werkzaamheden en de onze op elkaar werden afgestemd, alsmede voor de technische hulp die ze steeds zo bereidwillig verleenden.

Zonder de voortreffelijke medewerking van mejuffrouw GEKE VAN ZAND en de heren G. GARMING en W. F. BOUMA zou dit onderzoek niet mogelijk zijn geweest. Mejuffrouw VAN ZAND ontpopte zich hierbij als een medewerkster met bizonder veelzijdige hoedanigheden, daar zij niet alleen in staat bleek gedurende verscheidene jaren het koken en beoordelen van aardappelen goed uit te voeren, maar bovendien zeer veel rekenwerk en al het typewerk voor haar rekening nam op een wijze die boven alle lof is verheven. De heer GARMING bleek ongeëvenaard in het uitdenken van meetmethoden maar bovendien in de nauwkeurigheid, waarmee hij zich kweet van alle werkzaamheden, hetzij laboratorium- hetzij veldwerk. Behalve hun, ben ik ook de heer BOUMA, die helaas slechts in een deel van dit onderzoek kon assisteren en behalve de omvangrijke veldwerkzaamheden ook vele tijdrovende metingen tot een goed einde bracht, zeer dankbaar. Ik hoop dat zij, evenals ik, met veel voldoening op dit onderzoek, dat zonder haperen in een zo voortreffelijke sfeer werd uitgevoerd, zullen terug zien.

De heer DRS. L. F. C. FRIELE van het Vezelinstituut T.N.O. te Delft ben ik zeer erkentelijk voor zijn critiek en suggesties inzake de zo moeilijke materie van de kleurmeting.

De heer J. STEENBERGEN komt dank toe voor de wijze waarop hij het tekenen van de grafieken voor zijn rekening nam en de heren G. BIERLING en J. H. RUTGERS van het Bureau voor Gemeenschappelijke Diensten te Wageningen voor de bereidwilligheid om het fotografische materiaal te verzorgen.

Een woord van dank voor mevrouw P. DE WAARD-DEKKING te Groningen voor de wijze waarop en de snelheid waarmee zij de Engelse tekst corrigeerde is zeker op zijn plaats.

De mate waarin HESJE, MAURITS en CARIENTJE hun belangstelling voor „het dikke boek" steeds toonden was voor mij een bizondere aansporing om over enkele dode punten heen te komen, wat eveneens gold voor de belangstelling van mijn echtgenote, die een steeds stijgende verwondering toonde over het verschijnsel dat aan een in haar ogen zo oninteressant product zo veel te beleven was.

CONTENTS

PART IV – DISCUSSION AND CONCLUSIONS

PART I

INTRODUCTORY CONSIDERATIONS

1. INTRODUCTION

Anyone who is concerned with quality judgment by sensory methods will meet with difficulties in answering general questions such as: which characteristics of the product are worthy of judgment, which is the best way to perform the judgment, how can the number of samples be raised without losing too much in accuracy, how are judges kept in a good form, how can a constant judgment be obtained, etc. The product he is working with will also give rise to problems on the subject of representativity and preparation of samples.

During a period of six years of investigations about the influence of agricultural factors on the cooking quality of potatoes, in which period several thousands of samples were tested, we regularly encountered these questions and as a result of this the wish grew to replace the present sensory judgment of certain quality characteristics by instrumental methods or at least to use the latter as complementary methods to the sensory judgment. Of course it is not possible to give a complete solution after some years of investigations but the primary object of this research is to investigate the possibility of such methods.

Before discussing in detail the reasons for the necessity of instrumental methods and their advantages and disadvantages, it seems advisable to give in a few words an explanation of the conceptions of cooking quality and quality characteristics of potatoes as we see them.

Quality in general may be considered as the degree in which a certain product meets the demands of the consumer. In the case of potatoes cooking quality may be considered as the degree in which the properties of cooked potatoes will fulfill the requirements of the consumers. As the requirements of consumers in different countries are not in the least identical, while demands of consumers of the same country may also diverge rather strongly, it is clear that no research worker will readily judge the cooking quality of potatoes in such terms as good or bad, because whatever his verdict may be, a certain percentage of the consumers will disagree with him. As this percentages rises the opinion of the research worker will have less reason of existence. Since very little is definite about the consonance in judgment among consumers, the research-worker will do better not to give his opinion in words such as good or bad but rather in terms as no, little, rather and very. By this is meant that he indicates the intensity of the quality characteristics present in the sample, in other words he tries to describe the quality properties of the product quantitatively, after which the person asking for the judgment of the research worker will have to translate the descriptive terms into terms of appreciation. On the latter terms this person will form an overall judgment about the quality of the potato, but only as far as he sees it.

The question arises which properties of the cooked potato have to be considered as quality properties. In a meeting of february 1958 several European experts in the field of potato quality research decided that the following properties may be considered important: colour, discoloration, disintegration, consistency, mealiness, dryness, structure, flavour and (separate from the latter) off-flavour (LUGT and GOODIJK, 1958). To prevent misunderstanding something more should be said about these properties.

By *colour* is meant the colour of the cooked potato immediately after cooking, thus before a possible discoloration may influence the original colour. This colour varies from practically white (or better grey) to a very deep yellow. A better name would be yellowness. This yellowness is not evenly distributed throughout the tuber: the outer layer is a deeper yellow than the more central parts. This difference in yellowness between different parts of the tuber is probably for the main part a variety characteristic.

Discoloration will develop gradually in cooked potatoes of susceptible samples after the tubers have been put down on the plates and will reach its maximum after about a quarter of an hour. The discoloration may vary from a light grey till a very dark blueish grey and is mostly concentrated in the stem-end region of the tuber. Therefore it is often called stem-end blackening. In this part of the tuber the outer layers show more discoloration than the inner tissue. Occasionally discoloration is seen in the whole potato, not only in the outer layer but also in the interior.

Disintegration is a somewhat misleading term, because consumers in countries in which mealy potatoes are preferred will probably understand by disintegration a falling apart of the whole tuber, while consumers in countries in which a less mealy potato is preferred mean a disintegration of the outer layer of the potatoes. In the Netherlands a special term is used if the outer layer of the potato has disintegrated. This is indicated by the adjective „bloemig".

As *falling apart* during steaming of the potatoes is seldom observed in other countries but regularly occurs in the Netherlands this term will be maintained.

As for the disintegration of the outer layer the suggestion of LUGT (1961) will be followed by adopting the term *sloughing*. This offers two advantages viz. in the first place that misunderstanding is prevented and in the second place that this is the same term as is regularly used in American literature. In the case of moderate sloughing a certain part of the outer layer will remain intact causing a smooth appearance of that part of the tuber, while the other part of the tuber shows a more or less crumbly exterior in which case the outer layer has fallen from the tuber or is in the form of a loosely hanging "skin" connected to the rest of the tuber. When sloughing occurs in a lesser degree this remains limited to clefts in the outer layer and when disintegration is complete the whole outer layer has fallen from the potato.

The term *consistency* is used to indicate something about the cohesion of the tuber and is estimated by the resistance which is felt when a fork is pressed sideways through the tuber. This consistency is caused partly by the toughness of the outer layer of the potato (which is especially the case in mealy potatoes) and partly by the cohesion of the interior (especially in less mealy potatoes). By this contribution of two components it often happens that whole tubers get a figure for consistency which does not agree very well with the figure given after tubers have been halved. This causes frequent difficulties in judging this property, apart from the fact that this characteristic is already difficult to estimate as differences in consistency between tubers of the same sample, which often are very great, cannot be eliminated by preparing a mixture of the sample as is possible with some other quality properties. As, moreover, consistency is greatly influenced by method and duration of cooking it is clear that it is rather difficult to get a reliable estimate of this property.

In this thesis the term consistency has been replaced by the term *softness*. This has been done to compensate for the lack of logic in the judgment scale of the international working group formed by the experts mentioned earlier. This scale is based on the fact that low figures represent a low intensity in characteristics, but consistency forms an exception, as in this case a "one" for consistency means high consistency instead of low consistency. Therefore a term has been chosen which means the reverse of consistency.

One of the most important quality characteristics is *mealiness*. By this we understand the degree of crumbling of the potatoes after the cooked samples have been mashed with a fork. Mealy potatoes will upon mashing fall apart into small dry crumbs which show little coherence to each other or to the plate and which display a glistening white surface. By this lack of cohesion a fork can be stirred very easily through the mass. In non-mealy potatoes big lumps with a strong mutual cohesion and a strong adhesion to the plate will form. These lumps show no glistening white but a more or less wet surface. Stirring with a fork cannot easily be done.

Dryness, which term speaks for itself, can be estimated either visually (by judging the surface of a halved potato) or in the mouth.

Structure is the degree of granulation felt in the mouth. This granulation is probably caused by the size of the lumps of cells originating during rubbing of the tissue between tongue and palate. To prevent any misunderstanding about the meaning of the figures of the judgment scale we prefer to use the term *coarseness of structure*.

2. ADVANTAGES AND DISADVANTAGES OF SENSORIAL AND INSTRUMENTAL METHODS

In this chapter something more will be said about the reason for our wish to employ instrumental methods for the estimation of certain quality properties or to use these methods as a supplement to the sensory methods. At the same time an attempt will be made to weigh the advantages and disadvantages against each other.

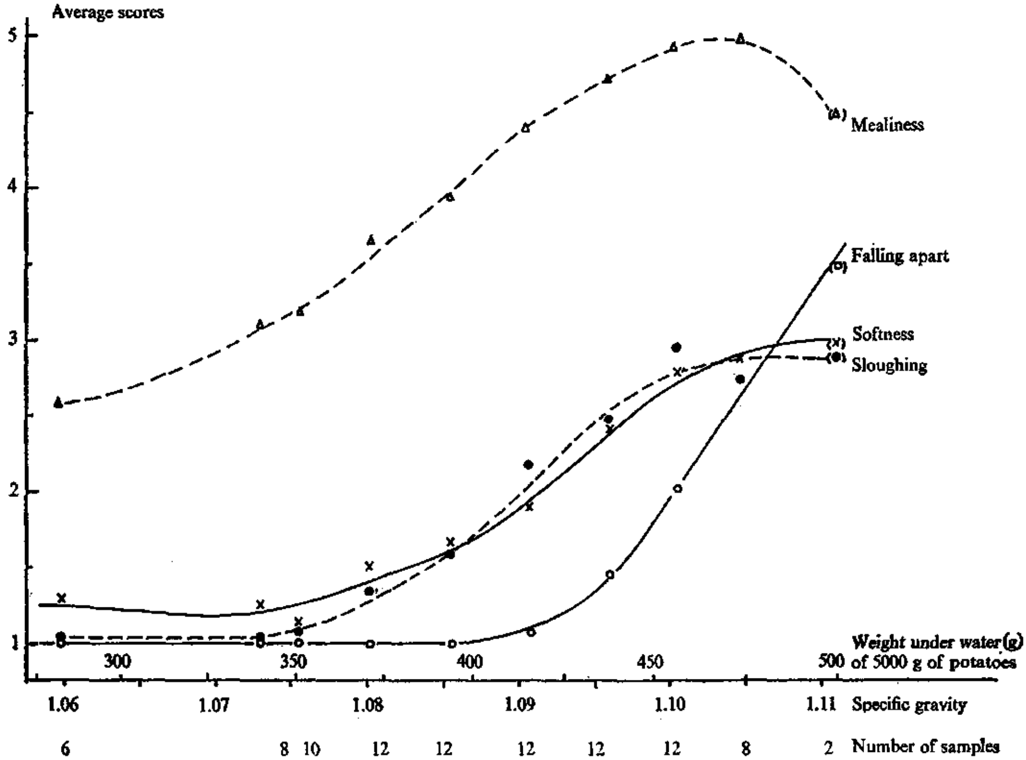

Fig. 1. The average relation between specific gravity (weight under water) and scores for quality properties (as judged in a scale of 5 points) of 6 lots of the variety Libertas after dividing the lots into specific gravity groups (samples of 1960).

The difficulties and uncertainties we met with during the last few years may be contributed partly to the potato and partly to the judges or their senses.

The first difficulty is to sample the potatoes for cooking. As is known from literature some quality properties are related to specific gravity (as a measure for dry matter or starch content) of the potato, although authors (see chapter 4) are not unanimous about the value of this relation. As specific gravity of separate tubers from the same lot varies considerably and as it is not permitted to use samples of sufficient size to eliminate this influence, representativity is not guaranteed. The size of the sample is determined by the necessity to cook the potatoes in one layer to prevent the influence of the tubers on each other (pressure), while in the case of tasting the susceptibility of the senses for fatigue has as a consequence that only a few tubers of each sample can be judged. Figure 1 demonstrates the relation between specific gravity of some samples of potatoes of the variety Libertas which were divided into several specific gravity classes and which were judged lot for lot, subsamples of each lot being placed on a table at random between other samples (SCHIPPERS, 1963b). It is clear that figures will often be obtained which may deviate rather strongly from the mean value of the lot if samples of only six, seven or eight tubers are selected at random, the more so as we see how specific gravities are distributed quantitatively (figure 2). This is especially the case with softness because variations in this property often are very great and softness has to be determined separately with each tuber. In the case of the remaining characteristics this is experienced to a lesser degree either because a well mixed sample may be obtained by mashing (mealiness, dryness, structure) or by the fact that the intensity of the property may be established at a glance (colour, discoloration, sloughing).

Some remarks must be made about the figures. Figure 2 tells which weight percentage of the lot is below a certain specific gravity limit. (For the benefit of those who are better acquainted with the weight under water of 5 kg of potatoes than with specific gravity this quantity has been mentioned next to specific gravity along the abscissa). The range in specific gravity agrees well with the figures of YOUNG (1962). It is clear that specific gravity in one lot of potatoes varies considerably. Even if we would discard 25 % of the tubers with the highest and 25 % of the tubers with the lowest specific gravity we still would not obtain a lot with uniform cooking quality, because specific gravity would vary in a range of something over 0.01, which means a range of about 50 grams in weight under water. From figure 1 it can be seen that a range of this length would correspond with a range of about one point (on a scale of 5 points) in intensity of some quality properties. Nevertheless in this way a considerable improvement would be obtained.

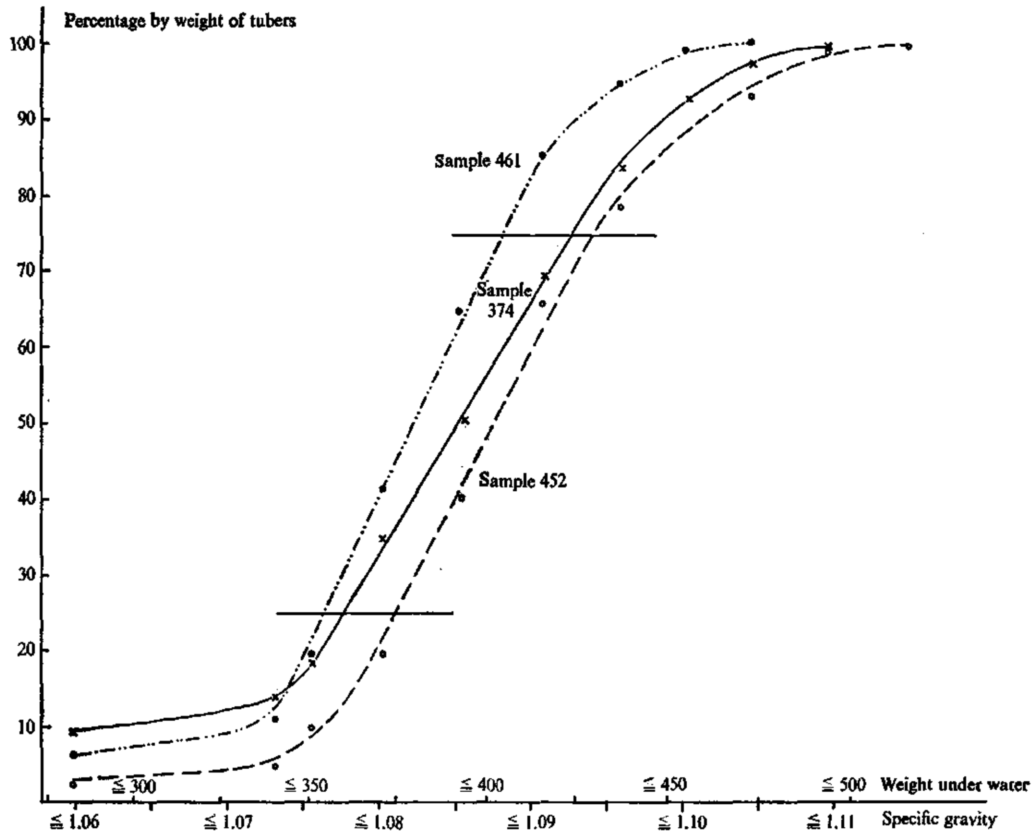

Fig. 2. Specific gravity characteristics of three lots of the variety Libertas in 1960.

Still, sampling is only a minor problem, because in general satisfying results are obtained by judging three random samples of each lot, samples being cooked on different days (SCHIPPERS, 1963b). Besides in this way a second favourable effect will result, viz. elimination to a certain degree of the influence of small differences in cooking time on texture properties. In fact, it is very difficult to fix accurately the moment when potatoes are exactly done. In practice doneness is determined by pricking a needle into the potato and feeling the resistance. A refinement is obtained by placing a stethoscope on the potato before pricking. Then a bursting of the cell walls is heard if the potatoes are not quite done, whereas in potatoes which are done a weak rustling is heard. In the latter case the needle is evidently penetrating between the cells. But even with this refinement it is not possible to determine the point of doneness exactly, mainly because often tubers of the same sample are not all done at the same moment. Then we have to choose between tolerating one or two underdone potatoes and preferring a sample with some overdone tubers. In practice the latter possibility will probably be chosen.

Another point must be discussed, viz. the difficulties arising from the persons who perform the judgment of the potatoes, or more precisely, the difficulties caused by the senses of the judges. These difficulties may be summarized by the following questions. Is it possible to judge each quality characteristic in such a way that we are sure that judgment is not influenced by some of the remaining quality properties? Which is the maximum number of samples to be judged daily without occurrence of fatigue of the senses? How many judges are needed for a reliable judgment? Given a certain scale for judgment, is a constant interpretation of this scale warranted? Will different judges interpret the scale in the same way?

The answers to several of these questions are difficult to give. Nevertheless on the strength of our experience of six years' research in this field we permit ourselves to give our opinion although we are not able to prove its correctness.

In judging colour we regularly experience difficulties caused by a quickly occurring discoloration or by a certain degree of disintegration. In judging mealiness the colour of the potato may play a part and probably also softness. Very strong is, we think, the influence of discoloration on the appreciation of flavour and the influence of flavour on all properties which are judged by taking the potato tissue in the mouth. Although we never tried to establish these influences quantitatively it may be assumed that several properties exert an influence on the judgment of other properties and that it is not likely that judges are able to separate all quality characteristics during judgment.

The lack of proof refers also to the second question, namely which is the maximum number to be judged daily without the occurrence of fatigue of the senses. During the first years we judged at the utmost 20 or 24 samples a day, half in the morning and half in the afternoon. As we found in this way significant and logical agricultural influences (SCHIPPERS, 1961, 1963a) we may say that our senses did not get overfatigued. Last year the number of samples was raised drastically to 64 a day, but we were only able to do this by omitting all quality properties which are judged in the mouth. Again significant agricultural factors were demonstrated (SCHIPPERS, 1963c) but it must be said that such a number is not advisable if dryness, structure and flavour are to be judged or when judges are not very experienced. Besides if one does not agree with our system of placing the samples on a table and judging them all at the same time (see paragraph 5.3.) but prefers to judge each sample separately, this number cannot be reached because of the dullness of the latter method.

On the question of the size of the panel we can be brief. As no one was available but my secretary and me, judging had to be done by two persons. It must be admitted that this basis is a bit weak, but nevertheless we worked in this way very satisfactorily during six years. The advantage is that we do not know the potato from hearsay.

Two questions which are also important and which can be answered to a certain extent more accurately are whether a judgment scale is always interpreted by one and the same judge in the same way and whether different judges will interpret the same scale in the same way.

In the winter of 1960/61 the quality properties of 29 samples of potatoes were judged ten times by two judges (see paragraph 5.1.) in a scale ranging from 1 (= not mealy, not sloughing, not yellow, not dry etc.) to 5 (= very mealy, completely sloughing, deep yellow, very dry, etc.). To prevent recognition these samples were placed between samples of other varieties. In this way the cooking and judgment of the 29 samples was spread over two days. As this was repeated ten times the whole investigation lasted twenty working days, that is about four weeks. The 29 samples consisted of ten varieties, separated into three or four specific gravity fractions. Specific gravity ranged from 1.050 (weight under water 240 g) to 1.110 (w.u.w. 495 g).

The three main effects in this experiment were "samples", "replications" and "judges." As cooking and judgment of all samples of one replication lasted two days, the main effect "replication" may be considered as an influence of time.

As was to be expected the greatest influence on quality properties was exerted by "samples", variances being three to thirty times as great as variances caused by the time factor. These main effects were significant for all eight quality properties, but the influence of "judges" was nonsignificant. As, besides, an interaction between the time factor and judges occurred only with mealiness and dryness and this interaction was of little practical value, it can be said that judges agreed about the direction of the time influence. Figure 3 gives a picture of the latter influence on some properties of cooking quality.

The question arises if the influence of time can be analysed by dividing the variances caused by this influence into their linear, quadratic, cubic, etc. components. As the error variance was very small, several components proved to be significant, which would mean that the nature of the influence remains obscure. However, if we express the variances caused by the different components in fractions of the variance of the component exerting the greatest influence, a clearer picture will be obtained. Table 1 gives the results of this calculation.

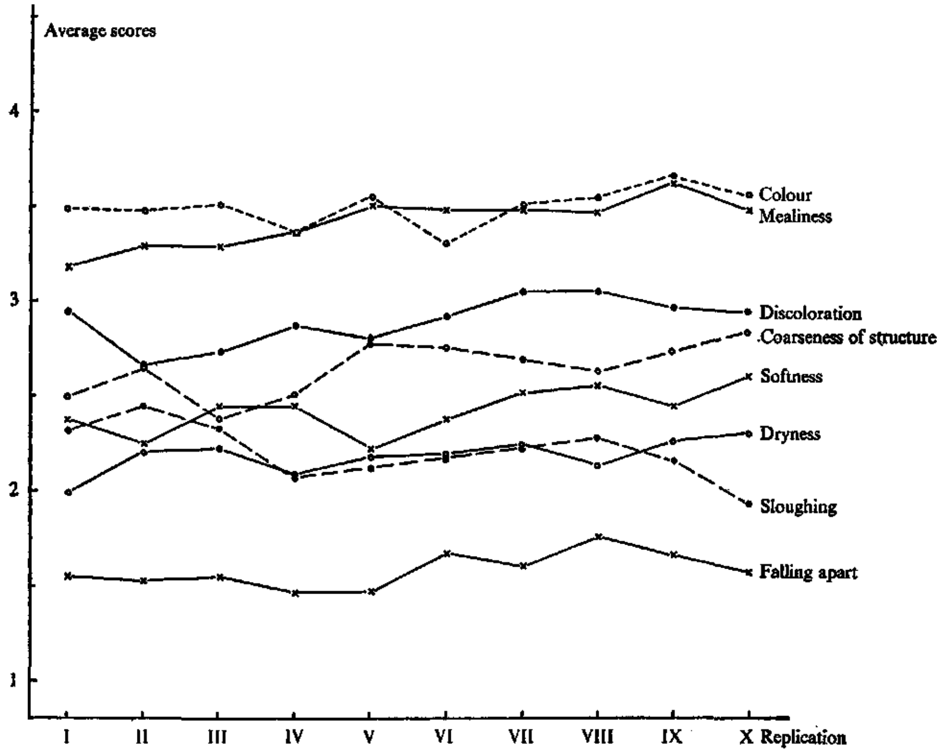

Fig. 3. The relation between the scores for quality properties (as judged in a scale of 5 points) and replications (= time factor) averaged over 29 potato samples. (Dutch variety trial 1960).

Table I

Component variances in proportionate numbers of the influence of replication (= time factor) on the scores of quality properties (as judged in a scale of 5 points) (Dutch variety trial 1960)

	Linear (1 d.f.)	Quadr. (1 d.f.)	Tert. (1 d.f.)	Quart. (1 d.f.)	Quint. (1 d.f.)	Rest (4 d.f.)
Mealiness	1	0	0.01	0	0.01	0.03
Coarseness of structure	1	0.24	0	0.30	0.15	0.20
Dryness	1	0	0.38	0.11	0.34	0.14
Sloughing	1	0.07	0.38	0.63	0.24	0
Falling apart	0.85	0.03	1	0.20	0.07	0.19
Softness	1	0.01	0.01	0.01	0	0.37
Colour	0.53	1	0.16	0.01	0	0.45
Discoloration	0.97	0	1	0.16	0.05	0.11

From this table and figure 3 we may conclude that in the course of a month the values of average judgments of several quality properties show a rectilinear increase (mealiness, coarseness of structure, dryness and softness), while only in the case of sloughing a rectilinear decrease is observed. The increase in the values for falling apart and discoloration is partly explained by the linear and partly by the tertiary component. Also in some other properties the linear course is accompanied by other influences, but these influences are of minor importance, e.g. coarseness of structure, dryness and especially sloughing. Only in the case of colour the quadratic component plays a part, accompanied, however, by the linear component.

The question arises which causes this shifting in average level of the samples.

Three causes may be indicated, viz. a gradual changing of the chemical composition of the tubers as a consequence of physiological events, a gradual shifting of the interpretation of the scale by the judges, and a gradual and unperceived modification in the cooking method.

Unfortunately these three causes cannot be separated, but it can be shown that each of them may play a part. For instance, in our experience sloughing and mealiness generally show a high positive correlation, but from the graph it can be seen that mealiness increased but sloughing decreased. Likewise we know that softness and sloughing are positively correlated although in the graph the lines diverge. Therefore it must be assumed that the interpretation of the scales for mealiness and softness on the one hand and the interpretation of the scale for sloughing on the other have been changed by a shift in the appreciation of the descriptions to which the points of the scale refer. Would a change in the composition of the potato during the four weeks of this investigation have been responsible for the linear course of the influences, then the lines for sloughing, mealiness and softness would probably have been parallel to each other. Moreover it is our experience that in the course of the winter months the potatoes become a bit firmer and do not fall apart so quickly during or after cooking. The figure suggests the contrary. Incidentally it may be remarked that specific gravity did not change linearly or quadratically during this investigation. As, averaged over replications, several texture properties were highly correlated with specific gravity, this means that the increase in mealiness, coarseness of structure and dryness cannot have been caused by a change in specific gravity. About the remaining cause, viz. a gradual and unperceived modification in the cooking method, the following may be said. As softness increased linearly and falling apart of the whole tuber increased too, although the tertiary as well as the linear component were significant, it could be asked if in the course of this investigation the cooking time involuntarily became longer before the tubers were considered done, assuming of course that the composition of the tubers did not change. As will be seen in paragraph 5.4.2. a method for measuring softness has been tested during this investigation. Irrespective of the value of this method it is interesting to note that softness as measured by this method increased linearly in the course of the investigation, as may be seen from figure 4. The correlation coefficient between the average figures per replication obtained by sensory judgment and the average figures obtained by this instrumental method was 0.919. As the latter method may be considered objective it is clear that softness of tubers did increase in the course of four weeks, but as this increase is contradictory to our experience that tubers become firmer during storage, it must be assumed that a gradual increase in cooking time has indeed occurred.

In figure 4 it is shown by the other lines that a strong shifting of interpretation of the scale has taken place. These lines indicate the glistening,

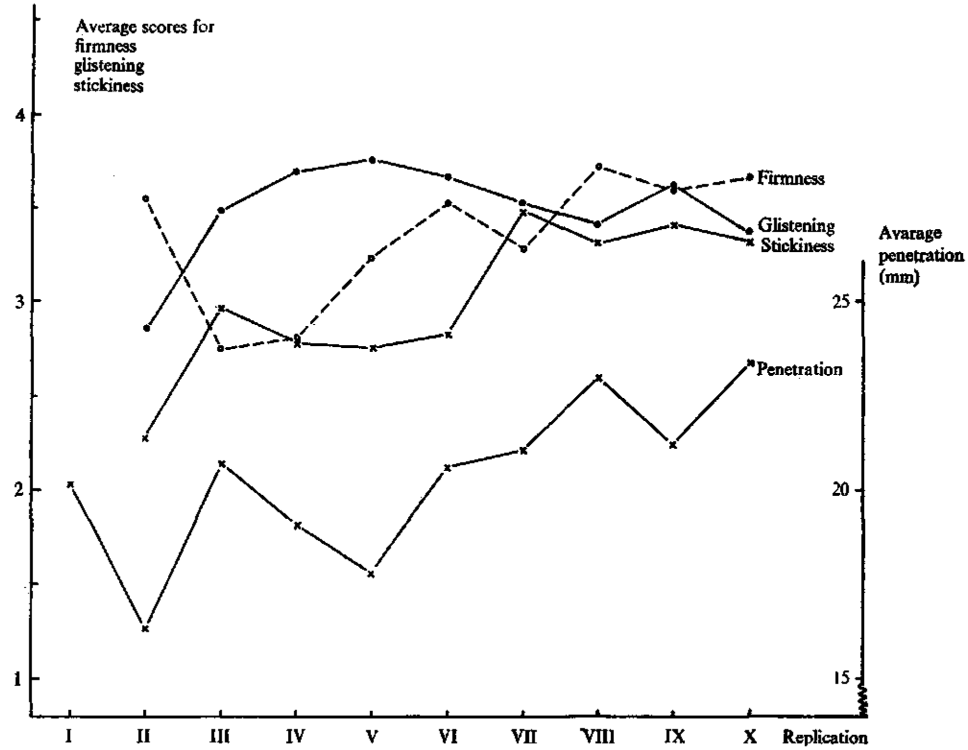

Fig. 4. Relation between replications (= time factor) and *a* scores for firmness, glistening and stickiness (as judged in a scale of 5 points) of a cilinder of potato tissue, *b* mm penetration of a falling rod, averaged over 29 potato samples. (Dutch variety trial 1960).

firmness and stickiness of cylinders of potato tissue, obtained by pressing mashed potatoes through a hole of 4 mm diameter. Variance analysis revealed that stickiness increased linearly, that the significant linear increase of firmness was accompanied by a rather strong tertiary influence and that the reaction of glistening was quadratic. That shifting of interpretation must have occurred is shown by the fact that for example the lines of stickiness and firmness run parallel, while the correlation coefficient between these characteristics proved to be negative, namely −0.875, if calculated from the averages per sample over the ten replications. That shifting in these cases has been much stronger than while judging whole potatoes may be contributed to the fact that the former judgment type was quite new. In judging glistening of the tissue, for example, one could conclude that a process of adaptation had taken place which ended after about five replications.

Taking all possible sources of error into account one would think, that, in spite of significance with respect to samples, replications and some interactions, the variations in the scores of each sample must be considerable. To get some idea of this spread in scores, which may be expected in this type of work, the sample standard deviations of all quality properties of each sample were calculated. It turned out that the value of these deviations mostly varied from 0.15 to 0.65, standard deviations being in general rather equally spaced in this range, but some samples could regularly be found outside this range.

It may be asked how the distribution of the 10 scores of a sample is in cases of a high standard deviation. Therefore in table 2 some examples are given, namely two samples with the lowest and two with the highest standard deviation of each characteristic. The plusses and minusses in the table are due to averaging of the scores of both judges.

The spread in standard deviations as well as the high level of many of these seems disappointing, but regarding the latter it must be borne in mind that the standard deviation of the mean, obtained by dividing the sample standard deviation by $\sqrt{10}$, is 0.28 at the utmost. Mostly, however, a level of 0.20 is not exceeded, that is one fifth of one unity of the scale.

As to the variation in sample standard deviations it may be asked if this is caused either by the potatoes or by the judges. If caused by the former this would mean that some samples varied more in quality properties than others. As some texture properties are related rather strongly this would mean at the same time that the sample standard deviations of these properties (e.g. mealiness, dryness and structure) would show a certain degree of correlation. This, however, is not the case. In fact there is no relation at all between any pair of quality properties with respect to the level of the sample

Table 2

Distribution of scores of samples showing lowest and highest standard deviations for each quality property (judgment in tenfold) (Dutch variety trial 1960).

sample no	Scores for quality properties (in a scale of 5 points)																	sample standard deviation
	1	1+	1½	2−	2	2+	2½	3−	3	3+	3½	4−	4	4+	4½	5−	5	
colour																		
1112												3	7					0.121
1108												1	7	2				0.142
1133				1	1	—	2	2	3	—	—	1						0.563
1135							2	—	1	1	2	1	3					0.580
discoloration																		
1124								1	7	1	1							0.197
1127							1	3	5	1								0.211
1131							2	1	2	1	1	—	3					0.601
1140					6	1	—	2	—	—	—	—	1					0.648
falling apart																		
13 samples!	10																	0
1108			1	—	3	—	1	1	1	—	—	2	1					0.878
1132		1	1	—	3	—	3	1	—	—	—	—	1					0.891
disintegration																		
1107	10																	0
1131	10																	0
1127				1	—	1	—	3	1	—	3	—	1					0.671
1132							1	1	3	—	2	1	—	—	—	—	1	0.729
consistency																		
1113								3	4	2	1							0.249
1135								2	6	—	2							0.258
1130									1	—	—	—	2	1	2	3	1	0.580
1140								1	—	—	—	—	3	1	3	2		0.587
mealiness																		
1107	9	1																0.079
1120																2	8	0.106
1116								1	1	—	1	—	4	—	2	—	1	0.688
1130							1	—	—	—	2	—	—	—	2	1	4	0.871
dryness																		
1107	10																	0
1136	9	1																0.079
1130		1	1	—	2	3	1	1	1									0.528
1138	1	—	—	—	4	1	1	1	2									0.601
structure																		
1138													10					0
1124			2	1	6	—	1											0.290
1111	1	—	2	—	2	1	1	—	3									0.708
1123					1	—	1	—	2	—	2	—	4					0.709

standard deviations. Besides, as the parallel samples of the lot varied very little in specific gravity (owing to the classifying into specific gravity groups), considerable differences in texture properties within samples were not to be expected. As no grouping of raw tubers is possible for colour and discoloration, one would expect a higher level of sample standard deviation for these characteristics than for texture properties, but this is not at all so. This would mean that the cause of variation in sample standard deviations is to be found in the judges rather than in the potatoes. However, we have to account for one disturbing factor, namely the influence of cooking. This influence is not to be expected for colour and discoloration but undoubtedly for falling apart and sloughing. It can be proved that the more the tubers are susceptible to falling apart and sloughing, the higher is the sample standard deviation. So for these characteristics accidental differences in cooking time may at least be partly responsible for the variation in scores. For the remaining properties such a relation could not be established although it is possible that cooking method has a certain influence on these characteristics. Nevertheless it is thought that the reason for variations in scores should be sought rather in uncertainty of judgment than in cooking time or in tubers. This uncertainty of judgment is not surprising because for instance dryness and structure are judged with small pieces of the tubers, while judgment of mealiness is influenced by colour, discoloration and perhaps softness, and softness may show considerable differences between tubers. In view of the relative easiness of the judgment the reason for variation in colour and discoloration is, in our opinion, due in the first place to differences in tubers.

Nevertheless it may be assumed that in general differences between tubers as well as the uncertainty of the judgment and in certain cases the influence of cooking method may cause great variations in scores.

As, irrespective of the influence of cooking method and a possible influence of chemical or physical changes in the potato, we are rather sure that beside fluctuations caused by the uncertainty of the judgment our interpretation of the scale is not always constant, it can hardly be expected that different groups of judges – that is groups which are not in a position to compare repeatedly their interpretation with that of other groups, as happens to judges within a group – will judge the same samples of potatoes in an identical way.

A beautiful example is given by the results of the exchange of potato samples by the international working group "Potato Quality Research" of the European Association for Potato Research (see paragraph 5.1). In this case we have at our disposal the judgments of research workers of several

Table 3

Correlation coefficients between "station-scores" and averages of the working group (r_{x_ny}), regression of "station-scores" on the average of the working group ($b_{x_ny} + c$), standard deviation of regression coefficients (σ_b) and average scores of stations ($\bar{x}_n$) (International variety trials)

Experimental station	mealiness				softness			
	r_{x_ny}	$b_{x_ny} . y + c$	σ_b	$\bar{x}_n$	r_{x_ny}	$b_{x_ny} . y + c$	σ_b	$\bar{x}_n$
	1959							
1	0.95	1.22 y − 0.22	0.094	2.57	0.69	1.19 y − 0.78	0.283	1.88
2	0.88	1.12 y − 0.04	0.137	2.52	0.65	0.89 y − 0.07	0.243	1.93
3	0.90	1.07 y − 0.02	0.138	2.43	0.73	1.87 y − 1.74	0.406	2.45
4	0.92	0.79 y + 0.46	0.076	2.28	0.42	0.48 y + 1.34	0.239 1)	2.42
5	0.78	0.83 y + 0.31	0.151	2.22	—	—	—	—
6	0.89	1.29 y − 0.84	0.163	2.12	0.62	1.22 y − 0.38	0.353	2.36
7	0.94	1.16 y − 0.45	0.106	2.26	0.52	1.03 y − 0.41	0.041 2)	1.89
8	0.95	1.26 y − 0.40	0.097	2.50	0.83	2.14 y − 2.34	0.329	2.45
9	0.87	0.63 y + 1.04	0.081	2.48	0.75	1.30 y − 0.30	0.279	2.62
10	0.90	0.71 y + 0.34	0.077	1.97	0.13	0.16 y + 1.91	0.285 2)	2.28
11	—	—	—	—	—	—	—	—
	1960							
1	0.86	0.94 y + 0.45	0.122	2.63	0.87	1.05 y + 0.12	0.131	2.37
2	0.91	1.16 y − 0.12	0.113	2.54	0.80	1.28 y − 1.05	0.208	1.67
3	0.89	1.15 y − 0.29	0.126	2.35	0.58	0.47 y + 1.03	0.143	2.02
4	0.73	0.69 y + 0.88	0.149	2.50	0.59	0.66 y + 1.05	0.208	2.48
5	0.88	1.01 y + 0.12	0.120	2.44	0.82	1.32 y − 0.67	0.197	2.14
6	0.81	1.25 y − 1.05	0.204	1.86	0.70	0.98 y + 0.11	0.219	2.23
7	0.71	0.91 y − 0.35	0.194	1.74	0.19	0.30 y + 1.32	0.338 3)	1.87
8	0.86	1.22 y − 0.39	0.155	2.41	0.89	1.74 y − 1.30	0.195	2.41
9	0.88	0.97 y − 0.07	0.112	2.15	0.81	1.13 y − 0.31	0.181	2.09
10	—	—	—	—	—	—	—	—
11	0.84	0.56 y + 1.00	0.084	2.32	0.66	0.53 y + 0.94	0.137	2.08

$$y = \text{average judgment of each sample} = \frac{\text{(total of judgment of all stations)}}{\text{number of stations.}}$$

x_n = judgment of the same samples by station 1, 2, etc.

All regression coefficients significant at P = 0.01 except:

1) not quite significant (P = 0.10).

2) significant at P = 0.05.

3) not significant (P $\geqq$ 0.40).

European countries about the same material viz. about twenty potato samples, which were judged according to the same scale. Moreover, preparation of samples was about the same and the judgment dates did not differ too much.

As it may be assumed that the working-group-averages of each sample give a better picture of the "real" intensity of properties than the judgment of each of the nine or ten judges separately, a correlation and regression analysis with the judgment of the separate panels as "dependent variable" and the working-group-average as "independent variable" may reveal something about the agreement of the judges, and particularly about the interpretation of the scale.

These calculations have been performed with the results of mealiness and softness in the years 1959 and 1960. Table 3 gives the results of this analysis and in figures 5 and 6 parts of these results are shown.

If we study mealiness first we come to the following conclusions:

a. Correlation coefficients between "station-judgments" and average judgment is in most cases satisfactory (0.87–0.95 in 1959, only station 5: 0.78; 0.81–0.91 in 1960, only station 4: 0.73 and station 7: 0.71).

b. If the level of the correlation coefficient is considered as an estimate of the "correctness" of judgment, several stations seem to have given a better judgment in one year (mostly 1959) than in the other year (station 1: 0.95 in 1959, 0.86 in 1960; station 4: 0.92 in 1959, 0.73 in 1960; station 7: 0.94 in 1955 and 0.71 in 1960; station 8: 0.95 in 1959 and 0.86 in 1960; but station 5: 0.78 in 1959 and 0.88 in 1960). This interaction of station and year is again an indication of the correctness of the supposition that a constant judgment is not possible.

c. Although qualitatively the relations between average and stations are satisfactory, this is not the case if we look at the quantitative relations. In the first place considerable differences in level can be established. While the average of the working group was in both years about 2.3 the average of the different stations varied from 1.97 to 2.57 in 1959 and from 1.74 to 2.63 in 1960. Besides, the average scores of some stations differed considerably for both years, while other stations reached about the same value in both years. As the regression lines of e.g. the stations 1 and 6 in 1959 are approximately parallel, it may be said that the scores of former station were all 0.5 point higher than the scores of station 6. The same is true in 1960 for station 1 and 9.

d. While the differences mentioned in the last case may be very inconvenient, the fact that the lines show considerable differences in slope creates further difficulties, for it means that several stations have used different scales. For instance, it seems that station 10 used in 1959 a scale of three points instead of four and that station 6 actually used a scale of 5 points.

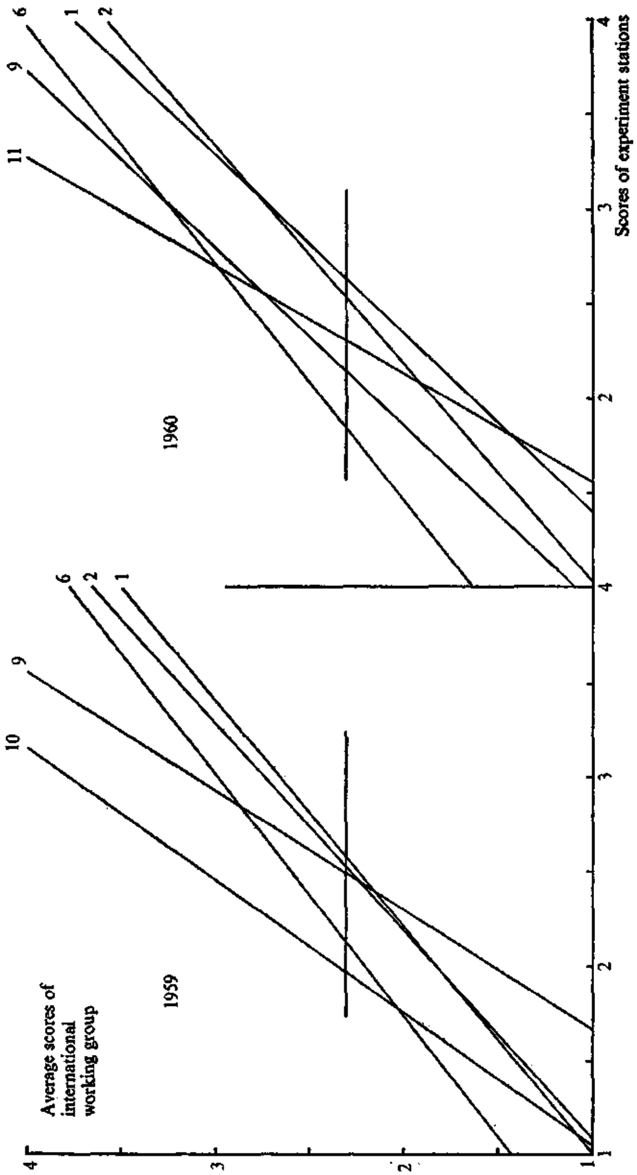

Fig. 5. Regression of the scores for mealiness of separate experiment stations (indicated by numbers) of the working group "Potato Quality Research" on the average scores of the whole working group. (International variety trials).

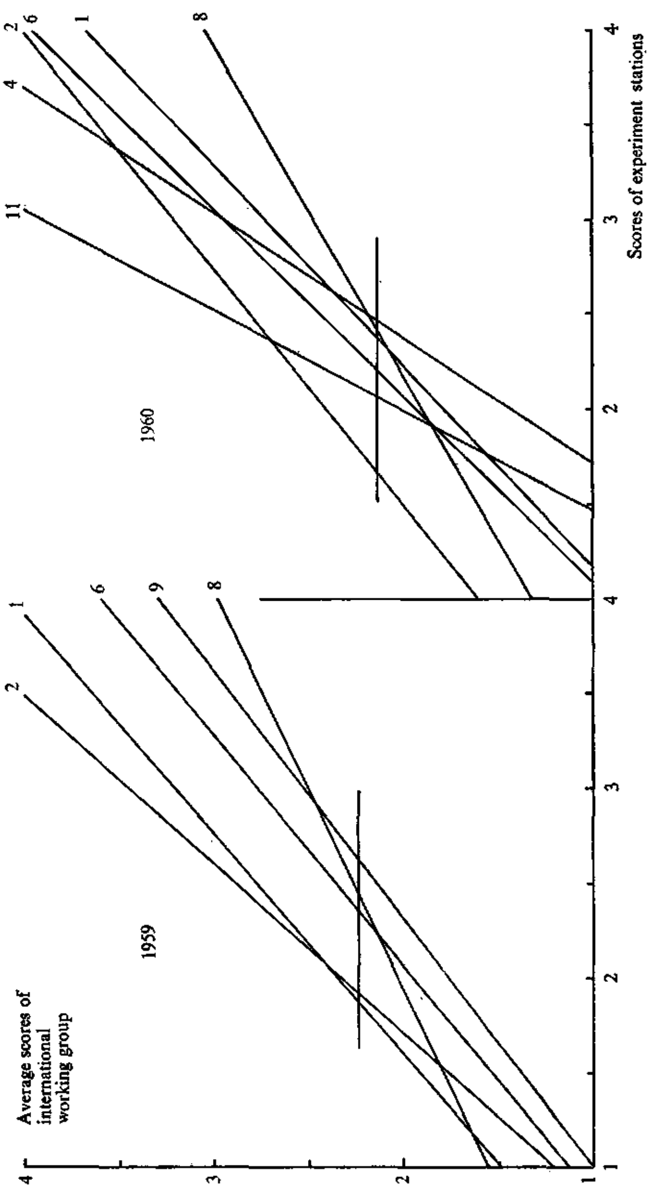

Fig. 6. Regression of the scores for softness of separate experiment stations (indicated by numbers) of the working group "Potato Quality Research" on the average scores of the whole working group. (International variety trials).

While softness gives principally the same results as mealiness, nevertheless the following remarks should be made.

a. Correlation coefficients between station-scores and average judgment vary considerably and the level of these coefficients is much lower than that of the corresponding coefficients for mealiness. This is to be expected because tubers of the same sample may vary considerably in softness and therefore too many tubers are needed to ensure representativity of the cooking sample. This characteristic is also strongly influenced by method and duration of cooking. Nevertheless results are very disappointing.

b. Differences in correlation coefficients of the same station in both years are much greater than corresponding differences in mealiness. The same holds for the interaction between station and year, but the correlation coefficients of most stations were higher in 1960 than in 1959, contrary to the results of mealiness.

c. Spread of station-averages being of the same order of magnitude as in the case of mealiness, differences in slope are much greater for the characteristic softness than for mealiness, indicating that differences in interpretation of the scale are more pronounced in the case of softness. Thus the slope of the line of station 8 in 1959 would make one conclude that a scale of 7 points has been used, while station 2 seems to have used a scale of $3\frac{1}{2}$ points.

The conclusion from this all is evident: apparently it is not possible – at least without prolonged and continually repeated training – to come to a uniform interpretation of a simple scale, which ranges from 1 (not mealy, not sloughing, etc.) to 4 (very mealy, completely sloughing, etc.). The consequence is that a certain figure for a given property will mean something different to every research worker.

On the basis of this rather extensive discussion the disadvantages of the sensory judgment as a method for estimating quality properties of cooked potatoes may be stated as follows.

a. In judging quality properties with the help of tongue and palate (flavour, coarseness of structure, dryness) the maximum daily number of samples to be judged by one panel is restricted. If judgment can be limited to properties not judged in the mouth the capacity is greater.

b. Because of the small size of the cooking samples representativity can only be obtained by cooking and judging several subsamples which limits the daily capacity still more.

c. The possibility exists that the judgment of several quality properties is influenced by the value of other quality properties.

d. In spite of considerable experience and continuous training a constant judgment is not guaranteed.

e. In the course of time the interpretation of the scale may undergo a gradual change, causing difficulties in investigations in which the time factor is important (e.g. influence of storage conditions on cooking quality, comparison of results of different years, etc.).

f. Without intensive and continuous training different (groups of) judges may differ in their interpretation of the scale. The question also arises, which research worker may claim correctness of interpretation. Therefore it is not possible to make recommendations to breeders about the question which intensity of quality properties is most promising, nor to technologists concerning the question which properties the tubers must have for technological purposes, etc.

g. The judges should be tested for their ability for this work.

As advantages of this method may be mentioned:

a. Preparation of the sample is very simple in comparison with chemical and most physical methods.

b. If judges are experienced, judgment will take little time.

The question now arises which advantages may be expected if it were possible to replace the sensory judgment of some properties by instrumental methods.

a. As fatigue of the senses will play no part the daily number of samples may be increased to the capacity of the number of personnel members.

b. Representativity may be improved as an increase in the number of subsamples is less difficult to obtain than in the case of sensory judgment.

c. Measurement of a property is not disturbed by the value of other properties.

d. A continuous training of the analysts is less necessary for obtaining constancy in results.

e. There is no danger for a shift in the use of the scale after the relation between the results of instrumental methods and the figures of sensory judgment has been established unambiguously. Therefore the time factor can be measured more accurately.

f. Interested people (plant breeders, technologists, consumers) need not ask for instance for a rather mealy potato, whatever they may mean by that, but instead can ask for a potato which gives certain numerical results obtained by a specified method. Also research workers may verify at regular intervals their sensory judgment by the results of instruments.

g. Testing of the senses of the judges is not necessary.

Against these advantages some disadvantages have undoubtedly to be set.

a. It is probable that the preparation of the sample for an instrumental measurement and the measurement itself will cost more in time and labour than the proceedings performed before and during the sensory judgment. Possibly measurement by instrumental methods will also cause more calculation work.

b. If quality research were to be performed by instrumental methods only, the danger arises that the research worker will lapse into a kind of meaningless automatism. In order to keep his work full of sense and to avoid an "estrangement" from the potatoes and from the consumer the measurement of cooked potatoes must regularly be accompanied by a sensory judgment.

PART II

TEXTURE PROPERTIES

3. THE RELATIONS BETWEEN TEXTURE PROPERTIES

As has been stated, the following properties, all connected with the texture of the tuber and therefore called texture properties, are estimated: sloughing, mealiness, dryness, coarseness of structure, softness and, if necessary, falling apart. If we want to devise instrumental methods to characterize them we may ask whether it is really necessary to develop methods for all these properties separately, or whether some properties are so closely related that one method might be used to measure several properties at once. In case of the latter possibility the question arises whether the properties which we estimate really are different and not one and the same property judged in different ways.

To get an idea about the relations between texture properties the correlation coefficients between falling apart, sloughing, mealiness, dryness and softness in samples of several variety trials in 1958 have been calculated. Table 4 gives the results of these calculations.

From this table it appears that certain properties are more clearly related to each other than others. For instance, correlation coefficients in which dryness is involved are mostly low, whereas correlation coefficients in which mealiness, sloughing, softness and falling apart are involved are much higher.

Table 4

Correlation coefficients between texture properties in samples of variety trials in 1958.

Correlation coefficients between	Experimental field no														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Falling apart and sloughing	.62	.83	.56	.77	.56	.32	.69	.68	.74	.59	.65	.45	.64	.78	.81
„ „ „ mealiness	.78	.71	.74	.77	.34	.40	.71	.67	.79	.62	.85	.52	.73	.81	.62
„ „ „ dryness	.15	.45	.51	.00	.39	.57	.53	.32	.16	.48	.70	.28	.72	.52	.05
„ „ „ softness	.76	.81	.61	.79	.05	.30	.79	.85	.53	.32	.77	.07	.56	.79	.80
Sloughing and mealiness	.74	.80	.53	.73	.79	.60	.69	.59	.78	.56	.87	.57	.63	.94	.82
„ „ dryness	.45	.85	.44	.04	.56	.40	.52	.09	.16	.45	.84	.25	.75	.68	.14
„ „ softness	.87	.88	.61	.83	.18	.34	.82	.88	.61	.64	.82	.59	.87	.94	.79
Mealiness and dryness	.61	.61	.62	.42	.66	.88	.79	.60	.58	.81	.89	.72	.87	.84	.51
„ „ softness	.83	.82	.80	.56	.11	.31	.71	.76	.44	.32	.83	.49	.54	.93	.71
Dryness and softness	.38	.39	.48	.14	.18	.13	.39	.29	.17	.07	.70	.09	.50	.73	.21
Number of samples	16	17	16	14	15	16	20	13	14	17	16	15	9	10	14

Of this latter group the correlation coefficients in which mealiness and sloughing play a part are somewhat higher than those in which falling apart and softness participate.

A second and more important conclusion which may be drawn is, that variation in correlation coefficients is considerable if we compare the results of the fifteen trials in this respect. This is not altogether satisfactory, because the question may be asked whether this variation is caused by variation in judging ability of judges or by real differences in the relations between texture properties. To get a better idea of the variation in correlation coefficients from field to field, dot charts have been subjected to a closer examination. From this it appeared that in many cases the level of the correlation coefficient was strongly influenced by one sample. Further examination showed that most of these samples belonged to one and the same variety and that the trouble was caused because sloughing of this variety was much higher than could be expected from the values of the remaining texture properties. This variety was found on the fields numbers 1, 2, 3, 4, 7, 8, 9, 10 and 12. On field 6 another variety was observed which reacted in the same way and on field 10 one variety was very hard in comparison with the remaining properties. On field 4 the correlation coefficient between mealiness and dryness was disturbed by the fact that three samples fell apart to such an extent that they could not be steamed dry, which resulted in much lower values for dryness than would have been obtained if this excessive falling apart had not occurred.

After discarding the above-mentioned samples (14 samples, of which 9 of one and the same variety, of a total of 122) the correlation coefficients concerned were recalculated. The results can be seen in table 5.

After this correction we may say that the correlation between sloughing and mealiness has reached a more satisfactory level, although the correlation coefficients still vary from 0.64 to 0.93. The remaining correlation coefficients vary even more. This means that we have to look for another explanation.

The first one would be that texture properties in potatoes from some fields actually show more coherence than in potatoes from other fields, but in our opinion this is too easy an explanation. The other explanation is that texture properties are always related to each other, but that because of a too small variation in characteristics the errors caused by the defectiveness of the judgment bring about an overshadowing of the real variation. Consequently a clear coherence between texture properties would only then be found, when differences between samples of a variety trial are sufficiently great to be observed.

If this supposition is correct we may expect a more or less proportional

Table 5

Correlation coefficients with (+) and without (−) disturbing samples
(Variety trials in 1958)

Correlation coefficients between	Experimental field no 1		2		3		4		6		7		8		9		10		12	
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
Falling apart and sloughing	.62	.73	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, ,, ,, softness	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.53	.72	—	—	—	—
Sloughing and mealiness	.74	.93	.80	.85	.53	.64	.73	.91	.60	.84	.69	.88	.59	.81	.78	.90	.56	.84	.57	.86
,, ,, dryness	—	—	—	—	—	—	.04	.71	.40	.74	—	—	—	—	—	—	—	—	—	—
,, ,, softness	—	—	—	—	.61	.68	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mealiness and softness	—	—	—	—	—	—	.56	.82	—	—	—	—	.76	.89	.44	.66	.32	.67	.49	.68
Dryness and softness	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.07	.39	—	—

relation between "texture coherence" and variation in quality characteristics, if these quantities are calculated per field. We now consider the average of the correlation coefficients[1] between all texture properties of the samples of one field as a measure for texture coherence and the average of the sample standard deviations of the texture properties of the same samples as a measure for variation in these characteristics. As we have in our case five texture properties this means that the measure for coherence is obtained by summing all mutual correlation coefficients and dividing them by ten, and that the measure for variation is obtained by summing the standard deviations of the texture properties and dividing them by five. If we do this with the data of each of the fifteen experimental field we can calculate the correlation coefficient between texture coherence and variation of the texture properties. It appears that this correlation coefficient is 0.800. This proves that in showing the existence of a coherence in texture properties the variation in these properties plays an important part.

It is possible that the variation in a certain texture property is not reflected to a sufficient degree in the correlation coefficients in which this texture property is involved, in other words, that the chance factor, because of difficulty in judging, overshadows, the "logical" variation. To test this, the correlation coefficient has been computed between the standard deviation of each quality property and the average of the correlation coefficients in which this property is involved. These coefficients proved to be 0.77 for falling apart, 0.80 for sloughing, 0.74 for softness, 0.50 for mealiness and 0.37 for dryness. Thus in the case of dryness especially its variation does not show a sufficient relation with the variation in other texture properties. This proves to be correct because if we calculate the correlation coefficient between texture coherence and the average variation of the texture properties after omitting dryness, this correlation coefficient is 0.925 (without omitting dryness it was 0.800). Either dryness is a characteristic which is difficult to judge correctly, which agrees with our experience, or dryness must be considered as a texture property which stands apart from the remaining properties.

Up to now we have considered the results of field trials with different varieties. These fields did not all contain the same varieties and this may also be a reason for differences in texture coherence between fields. We may now

[1] We are aware of the fact that from a mathematical point of view averaging of correlation coefficients is not exactly permitted, but as it is only the purpose to get an idea of the level of correlation coefficients between texture properties this simple method seemed justified to us.

Table 6

Correlation coefficients between texture properties

Correlation coefficients between	Varieties from variety trials in 1958									Samples from crops planted by farmers				
	Aristo	Asoka	Burmania	Libertas	Mulder-J 48/109	Noordeling	Surprise	Vedder 49/05	Woudster	Lib. '57	Lib. '58	Lib. '59	Ei.g '59	Bintje '59
Falling apart and sloughing	.55	.39	.60	.66	.16	.57	.53	.14	.28	.48	.50	.54	.60	.70
,, ,, ,, mealiness	.32	.04	.56	.39	.01	.25	.12	.41	.13	.35	.42	.10	.40	.54
,, ,, ,, dryness	.65	.24	.33	.07	0	.41	.57	.06	.02	.08	.15	.49	.32	.37
,, ,, ,, softness	.65	.04	.52	.39	.63	.70	.19	.34	.21	.79	.74	.76	.57	.57
Sloughing and mealiness	.13	.10	.79	.18	.37	.51	.36	.80	.78	.73	.71	.36	.81	.75
,, ,, dryness	.07	.09	.33	.25	.32	.53	.76	.63	.14	.31	.47	.07	.33	.70
,, ,, softness	.59	.59	.69	.41	0	.75	.05	.86	.37	.60	.61	.40	.69	.62
Mealiness and dryness	.12	.39	.19	.24	.21	.63	.24	.69	.01	.47	.64	.27	.36	.69
,, ,, softness	.70	.41	.50	.72	.68	.74	.37	.62	.24	.47	.55	.11	.58	.50
Dryness and softness	.44	.60	.41	.66	.13	.47	.19	.42	.11	.07	.21	.60	.08	.36
Number of samples	10	10	11	13	9	9	12	10	10	176	212	100	119	135

ask how the results are when we compare the results of the same variety, but grown on different fields.

Results will also be given of some varieties of which many samples, obtained from existing potato fields of farmers, have been tested. Table 6 gives the correlation coefficients between texture properties.

Comparison with table 4 reveals that the correlation coefficients in table 6 are in general considerably lower than in table 4 and that the variation in correlation coefficients when comparing different varieties is even greater than when comparing different fields.

Before going into the reason why these correlation coefficients are lower and the variation is greater we may point to the results, obtained with the variety Libertas in three successive years. The correlation coefficients of 1957 and 1958 agree very well, which means that our judgment, however faulty, has at least been very consistent. In 1959 some correlation coefficients deviate, which undoubtedly is caused by the abnormal growing conditions during that season. This resulted in potatoes with a very high mealiness and a very low standard deviation for mealiness. Therefore correlation coefficients in which mealiness was involved were much lower than in 1957 and in 1958. But also the remaining standard deviations were lower with the result that some other correlation coefficients were low too. That correlation coefficients of the variety Eigenheimer and Bintje in 1959 were much higher than those of Libertas in the same year, is undoubtedly due to the fact that the former varieties have been grown on clay soils which did not suffer from a shortage of water as did the sandy soils on which Libertas was grown.

Returning to the causes for the low level of, and the considerable variation in, correlation coefficients when comparing varieties, we may ask how "texture coherence" is related to "texture variation". Preparation of a dot chart shows that correlation is almost absent, but when the dots are brought onto the chart prepared for fields, the result is that the dots for varieties form a group which links very well with the existing dots for fields. This group shows a lower texture coherence and lower average standard deviations than the latter. Also if we compare the standard deviation of a certain property with the average of the correlation coefficients in which this property is involved, it appears that this correlation is much lower than if comparing these quantities of the fields, but again the dots form an extension of the existing group of dots. So it is probable that the relation holds, but that we are not able to show this as clearly as in the case of different fields.

As an explanation we may put forward the following reasons. As standard deviations within varieties are smaller than within fields it is possible that the uncertainty of the judgment plays a greater part. The fact that the relation

Table 7

Correlation coefficients between texture properties as calculated from judgments of members of the international working group "Potato Quality Research". (International variety trials)

Correlation coefficient between	Experimental station																		Keller and Béroes (1961)
	1			2			3			4			5			6			
	'59	'60	'61	'59	'60	'61	'59	'60	'61	'59	'60	'61	'59	'60	'61	'59	'60	'61	'59
mealiness and sloughing	.83	.75	.93	.82	.90	.72	.84	.74	.65	.77	.90	−.14	.95	.73	.66	.78	.68	.78	.63
„ „ dryness	.88	.82	.94	.95	.92	.79	.98	.95	.87	.75	.71	.85	.83	.71	.52	.78	.75	.62	.73
„ „ structure	.92	.74	.86	.81	.58	.77	.97	.89	.93	.75	.76	.54	.91	.81	.65	.62	.64	.38	.69
„ „ softness	.67	.66	.76	.51	.83	.84	.95	.81	.71	.55	.71	.59	.79	.48	.53	.60	−.24	.11	.45
sloughing and dryness	.77	.54	.86	.85	.82	.80	.82	.79	.71	.63	.53	−.20	.82	.70	.61	.77	.65	.67	.58
„ „ structure	.83	.75	.84	.67	.59	.55	.82	.78	.74	.70	.66	−.30	.83	.56	.58	.64	.37	.44	.48
„ „ softness	.81	.87	.74	.59	.84	.65	.83	.75	.80	.46	.72	.12	.82	.53	.65	.81	−.03	.39	.47
dryness and structure	.95	.76	.88	.73	.54	.47	.97	.91	.87	.63	.68	.49	.82	.80	.47	.55	.72	.37	.70
„ „ softness	.59	.47	.69	.56	.77	.59	.94	.79	.71	.42	.19	.32	.63	.26	.39	.53	−.46	−.03	.31
structure and softness	.62	.63	.74	.23	.70	.62	.91	.87	.79	.23	.27	−.02	.68	.21	.63	.63	−.57	−.05	.33

between standard deviations of e.g. mealiness and the average correlation coefficient in which mealiness is involved shows a curvilinearity – which means that with decreasing standard deviation this average correlation coefficient decreases more with low values than with high values of the standard deviation – also points in this direction. One factor, however, is particularly important, viz. that samples of one and the same field have been cooked and judged on one day, whereas samples of one and the same variety have been cooked and judged on different days. In the latter case differences in interpretation of the scale as shown in the preceding chapter may have played a part. Thus a greater part of the standard deviations has to be contributed to interpretation differences than in the case of variety comparison.

In conclusion we may say that a general rule concerning the relation of texture properties to each other could not be established, but that a lack of coherence between texture properties can be explained by lack of accuracy in the sensorial method. Consequently a lack of coherence, as is sometimes found by us, is no proof of a real absence of coherence. Evidently the finding of high correlation coefficients among texture properties is highly dependent on the material offered. This is supported by the figures given by KELLER and BÉRCES (1961). In 1957 they judged 75 varieties and in 1958 81. The correlation coefficient between for instance sloughing and dryness was in 1957 −0.68 but in 1958 +0.67, between mealiness and dryness 0.69 and 0.80 and between sloughing and mealiness −0.20 and +0.54 respectively.

One factor we just mentioned is the influence of interpretation of the scale. We may indeed ask ourselves if it is really possible to establish relations between texture properties correctly if we do not eliminate the personal interpretation of the scale. In chapter 2 we mentioned the exchange of potato samples by the international working group "Potato Quality Research" of the European Association for Potato Research. The results of this exchange provide unique material for a demonstration of the influence of personal interpretation on the relation between texture properties. Table 7 is prepared after calculating the correlation coefficients between texture properties on the basis of the judgments of some of the experimental stations. Correlation coefficients are also given which KELLER and BÉRCES (1961) calculated from the complete material, i.e. without eliminating station influences. As falling apart played no part in this material, this property has been omitted, but, contrary to our variety trials, coarseness of structure has been included.

It is clear from this table that, although all stations have tested the same lots of potatoes, correlation coefficients show great variations from station to station. But it also is evident that the correlation coefficients obtained by the same station in different years are not always constant.

This shows that interpretation differences play a much greater part than is generally assumed. This is proved by the last column in which the results of KELLER and BÉRCES (1961) are given. It can be concluded that the correlation coefficients found by calculating them on all available individual figures, are in nearly all cases lower than the correlation coefficients obtained by any of the six experimental stations in 1959. Undoubtedly this must be ascribed to the fact that when preparing a dot chart of the whole material showing the correlation between two texture properties, we will get the same picture as in figures 5 and 6, viz. differences in level of the groups of dots belonging to the different stations and differences in slope of the axis of these groups. Consequently the conclusion of KELLER and BÉRCES (1961) that in spite of relatively close correlations the relations between texture properties are too loose to justify the omission of one or more texture properties, has been drawn on the wrong figures.

A better idea about the real relations is obtained by following another calculating method. When obtaining regression lines as shown in figures 5 and 6, it is clear that no experimental station can claim an absolute correctness of its results (although experience may vary from station to station), so long as there is no objective method for measuring the quality characteristics of potatoes. It is just as obvious that there is only one way to diminish differences in interpretation of the scale, viz. by averaging the judgments of all stations about the same samples. In doing this we assume that the average judgment will give a better picture of the "real" quality than the judgments of the experimental stations could give separately, which to us seems justifiable in view of the present (lack of) knowledge about these matters.

Therefore correlation coefficients have been calculated between texture properties making use of the average judgment of all stations about the same sample. The results are given in table 8.

Although correlation coefficients of several stations varied from year to year and variation in correlation coefficients from station to station in the same year was even greater (table 7), the correlation coefficients based on the average judgments of the working group still show a very good agreement, if we compare the results of the three years.

Besides, it can be concluded that the correlation between some quality properties is very high, for instance those between mealiness and dryness, mealiness and structure and dryness and structure. In fact, the question may be asked whether these three quantities are not three names for the same

Table 8

Correlation coefficients between texture properties, calculated from average judgments of all experimental stations
(International variety trials)

Correlation coefficients between	1959	1960	1961
Mealiness and sloughing	.95	.94	.95
„ „ dryness	.97	.95	.95
„ „ structure	.95	.96	.92
„ „ softness	.83	.71	.76
Sloughing and dryness	.93	.86	.96
„ „ structure	.92	.90	.89
„ „ softness	.82	.86	.73
Dryness and structure	.95	.92	.87
„ „ softness	.79	.63	.67
Structure and softness	.73	.73	.72

property, only judged by different methods. It seems that softness stands a bit apart, because the correlation coefficients in which this characteristic participates are clearly lower than for the remaining properties. Sloughing occupies an intermediate position as the correlation coefficient between mealiness and sloughing is very high, between sloughing and dryness and between sloughing and structure a bit lower but still high, and between sloughing and softness again lower.

In concluding this chapter we may summarize as follows:

The relation between the texture properties mealiness, structure and dryness is so high as to make it probable that they are different names for the same property. Although softness is clearly related to these characteristics as well as to sloughing, this property occupies a more separate position, whereas sloughing is more related to the first mentioned three characteristics than to softness, although the correlation coefficient between sloughing and softness is also high.

That we need special conditions to show these correlations is due to the fact that a reliable judgment by sensory methods is very difficult to achieve. A panel of judges is only able to obtain high correlations if the material offers sufficient variation in its properties, although in that case the "station bias" resulting from the interpretation of the scale will mostly prevent obtaining correlation coefficients such as will be obtained when this bias is diminished by averaging the results of different judging groups.

Nevertheless, having based these conclusions on a relatively small amount of material, we have to account for the possibility that some varieties may show deviating correlations as was the case with one variety in our field trials of 1958, which sloughed too much in relation to the remaining texture properties. This is a conclusion which seems to us of interest especially for plant breeding.

4. THE RELATION BETWEEN SPECIFIC GRAVITY AND TEXTURE PROPERTIES

In literature on this subject there is little agreement about the relation between texture properties on the one hand and starch content, dry matter content (as an approximation of starch content) or specific gravity (as a still more inaccurate measure of starch content) on the other. BEWELL (1937) for instance, found a correlation coefficient of 0.45 between dry matter content and mealiness, CHILD and WILLAMAN (1929) calculated a correlation coefficient of 0.54 between specific gravity and mealiness, and DOW (cited by SWEETMAN, 1936) established a correlation coefficient of 0.62 between the last mentioned quantities. The correlation coefficients calculated by SHEWFELT a.o. (1955), HESTER and BENNET (1956) and UNRAU and NYLUND (1957) between specific gravity and mealiness were higher viz. 0.71, 0.70 and 0.74 respectively, but when specific gravity was replaced by dry matter or starch content UNRAU and NYLUND found values of 0.88 and 0.94 respectively. BETTELHEIM and STERLING (1955a) mentioned a still higher correlation coefficient between mealiness and specific gravity namely 0.83. HEINZE a.o. (1954), who found correlation coefficients of 0.72 (1948) and 0.86 (1949) between the same characteristics, state that the relation is sufficient to use specific gravity as an indication for the cooking quality which may be expected. They also mention a weak point in the investigations of those who found low correlations, namely too small a range in specific gravity to establish a reliable relation with quality properties. CHILD and WILLAMAN also seem to be of this opinion when they write: "It is apparantly not a question of dry matter, at least within the range studied here". Besides, most papers give very few particulars about the sensorial methods or about the number of replications which have been applied. This often holds also for the range in specific gravity. Recently CULLEN (1960) showed some very clear exceptions in the relation between mealiness and starch content, which relation, apart from these exceptions, was very good.

In the same material in which we calculated the relation of texture properties to each other we computed the correlation coefficients of the latter with specific gravity, determined by weighing 5 kg of potatoes under water.

Table 9 gives the result of these calculations.

Table 9

Correlation coefficients between specific gravity and texture properties in samples of variety trials in 1958.

Correlation coefficient between specific gravity and	Experimental field no															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	15[1]
Falling apart	.70	.76	.44	.72	.35	.54	.74	.69	.70	.78	.80	.23	.81	.84	.24	.32
Sloughing	.68	.84	.63	.74	.61	.29	.69	.56	.77	.62	.78	.71	.80	.81	.31	.58
Mealiness	.73	.85	.56	.80	.69	.64	.57	.69	.75	.57	.84	.56	.67	.87	.27	.49
Dryness	.29	.50	.47	.31	.78	.86	.66	.12	.40	.48	.85	.52	.85	.70	.45	.52
Softness	.74	.82	.40	.47	.28	.02	.57	.75	.60	.31	.64	.31	.70	.78	.12	.38

[1]) after eliminating one disturbing sample (see text).

From this table it may be concluded that the correlation coefficient between specific gravity and each texture property may range from 0.20 to 0.85. This is not very satisfactory, as it seems to suggest that the relations between specific gravity and texture properties are not fixed, but are dependent on other conditions. A second remarkable fact is that the correlation coefficients in the table seem to show a correlation between themselves if compared per experimental field. Thus, if one correlation coefficient in the table is high the remaining correlation coefficients of the same field are also high. The only exception seems to be the correlation coefficients between specific gravity and dryness although incidental exceptions are to be found in other correlations as well. It must be remarked that on three fields some samples caused great aberrations in the correlation coefficients. Recalculation without these samples resulted in the following changes. On field 4: 0.80 instead of 0.31 (dryness); field 6: 0.63 instead of 0.29 (sloughing); field 7: 0.82 instead of 0.57 (mealiness).

We have seen in the preceding chapter that texture properties are related to each other and consequently it is logical to assume that all correlation coefficients with specific gravity are of about the same level. That dryness makes an exception could be expected too because the correlations between dryness and the remaining texture properties were mostly lower than the correlation coefficients among the latter, at least in our variety trials.

So if correlation coefficients between texture properties and specific gravity are high, we may expect high correlation coefficients between the texture properties among each other. Examples of this case are fields 2, 11 and 14 (compare the correlation coefficients concerned of the tables 4 and 9). On the other hand we may ask if the correlation coefficients between texture properties can also be high when the correlation coefficients between texture properties and specific gravity are low, as is the case with fields 3, 12 and 15. In table 4 it can be seen that these correlation coefficients are rather low. In fact, the average of the correlation coefficients between the texture properties themselves gives a correlation coefficient with the average of the correlation coefficients between texture properties and specific gravity of 0.765. However, after elimenation of the interfering samples mentioned above, as well as a sample of field 15, which falls completely out of the group of dots when comparing texture properties and specific gravity, this coefficient increases to 0.812. This means that a combination of high texture coherence with low correlation between texture properties and specific gravity will not be found. This points to a relation between specific gravity and texture properties. Consequently it is expected that there must be a correlation between the standard deviation of specific gravity, calculated per field, and the average of the correlation coefficients between specific gravity and texture properties per field. Nevertheless thiss correlation coefficient proved to be 0.482. So, if samples are offered for judgment of texture properties, a great variation in specific gravity of the samples will hardly guarantee the finding of a relation between texture properties and specific gravity. This is confirmed by the fact that the variations in standard deviations of texture properties from field to field hardly show a relation with the variations in the standard deviations of specific gravity.

As along these lines no solution seems possible for the problem how texture properties depend on specific gravity and why texture properties show varying relations to each other, another approach has been tried, based on the assumption that variations in the quantitative relation between specific gravity and texture properties would be responsible for the variations in correlation coefficients, either between texture properties and specific gravity or between texture properties themselves. To trace this the regression of mealiness on weight under water has been calculated with the results of those fields which gave the best correlations between these characteristics, viz. field 2, 4, 11 and 14. The same has been done for dryness with the results of fields 4, 6, 11 and 13 and for falling apart with the results of fields 11, 13 and 14. Table 10 gives the results and figure 7 shows the lines.

These results are somewhat astonishing especially in the case of mealiness.

Table 10

Correlation coefficients between specific gravity and texture properties (r), averages of weight under water ($\bar{x}$) and of texture properties ($\bar{y}$), standard deviations of weight under water (σ_x) and texture properties (σ_y), regression of texture properties on weight under water ($b_{yx} . x + c$) and standard deviation of regression coefficients (σ_b).

(Variety trials in 1958)

field	number of samples	r	$\bar{x}$	σ_x	$\bar{y}$	σ_y	$b_{yx} . x + c$	σ_b
					Falling apart			
11	16	0.80	401	31.4	1.45	0.60	0.0154 x − 4.71	0.0030
13	9	0.81	445	26.8	1.72	0.89	0.0268 x − 10.19	0.0074
14	10	0.84	420	37.2	1.84	0.79	0.0207 x − 6.85	0.0029
					Mealiness			
2	17	0.85	416	26.4	3.47	1.08	0.0347 x − 10.98	0.0056
4	14	0.80	429	35.2	3.87	0.75	0.0141 x − 2.16	0.0028
11	16	0.84	401	31.4	3.48	1.17	0.0317 x − 9.21	0.0052
14	10	0.87	424	37.2	3.15	0.94	0.0221 x − 6.20	0.0045
					Dryness			
4	11	0.81	415	35.2	2.61	0.61	0.0137 x − 3.08	0.0035
6	11	0.86	409	28.7	1.80	0.60	0.0171 x − 5.19	0.0031
11	16	0.85	401	31.4	2.19	0.63	0.0171 x − 4.66	0.0028
13	9	0.85	445	26.8	2.75	0.41	0.0132 x − 3.11	0.0031

It can be seen that field 2 differs from field 11 only in level. This is true in a lesser degree when comparing fields 4 and 14, but the slope of the lines 2 and 11 is much steeper than that of the lines 4 and 14. In the case of falling apart all three lines show a different slope and in the case of dryness again two groups may be seen, but less clearly, viz. the lines 4 and 13 and the lines 6 and 11.

It may be asked whether differences in level and in slope as shown in the figure can have been caused by shifting in interpretation of the scale of five points which has been used. This can be investigated in a simple way.

As all samples have been cooked and judged two times and the second judgment was done several months after the first, a shifting in the interpretation of the scale would result in regression lines with clear differences in level or slope (or both), when comparing the lines of one and the same field. However, in figure 8 in which the regression lines of mealiness on specific gravity have been drawn it can be seen that although some differences in level and in slope are found, yet the interpretation of the scale on both dates was essentially the same, differences within fields being explained by an influence of storage.

So it seems that quantitatively the relation between specific gravity and texture properties is not constant, which is in agreement with previous investigations (SCHIPPERS, 1961), which showed that the influence of fertilization on texture properties was not always in accordance with the influence of fertilization on specific gravity.

Steep regression lines indicate that relatively small differences in specific gravity result in relatively great differences in texture properties, and less steepness indicates that greater differences in specific gravity are required to cause the same differences in texture properties. As the range of specific

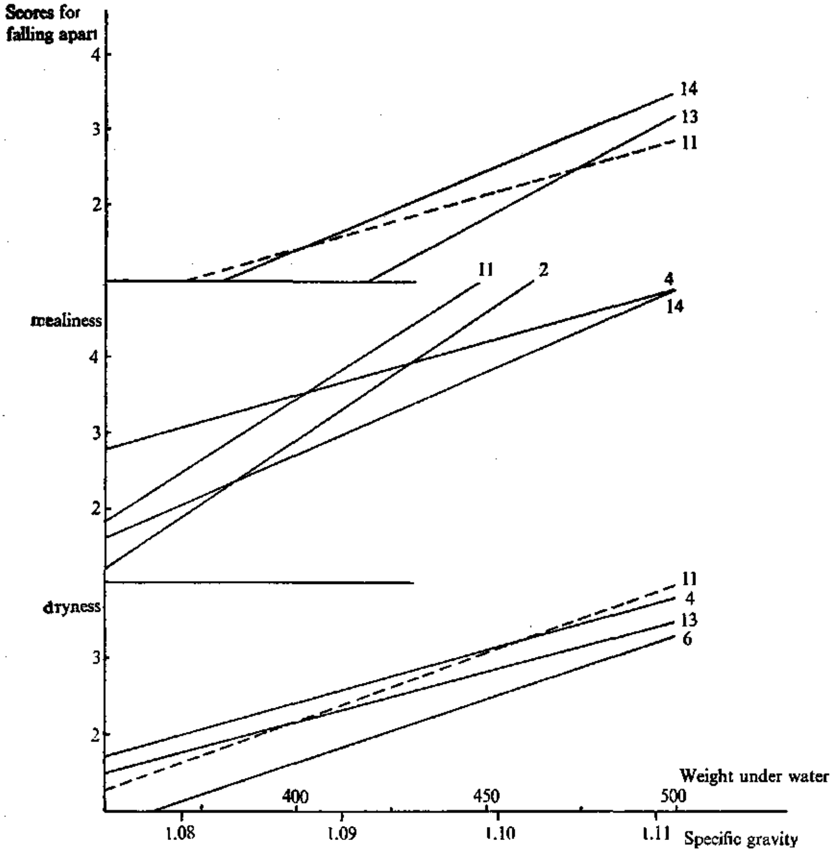

Fig. 7. Regression of scores for some quality characteristics (judged in a scale of 5 points) on specific gravity (weight under water) in samples of variety trials in 1958 (Numbers represent trial fields).

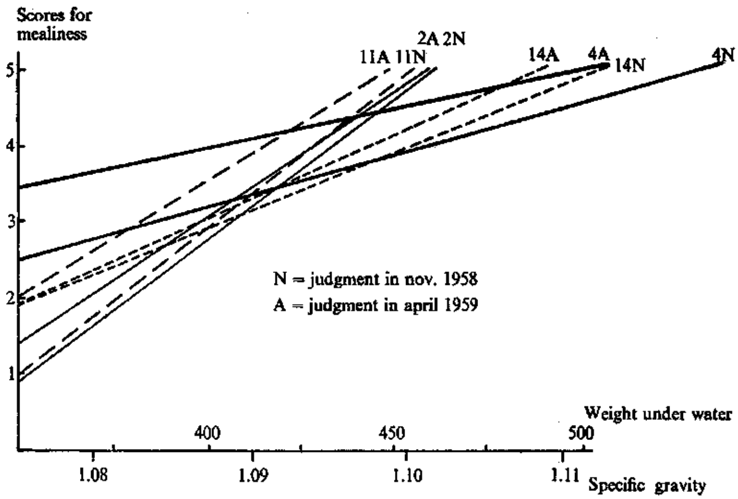

Fig. 8. Regression of scores for mealiness (judged in a scale of 5 points) on specific gravity (weight under water) in samples of variety trials in 1958 (Numbers represent different fields).

gravity of different fields for the most part shows small differences, this means that the standard deviations of texture properties in the former case will be greater than in the latter. Consequently if the real relation is such that the lines run still more parallel to the horizontal axis, standard deviation of texture properties will become so small that a reliable judgment is impossible or only possible in exceptional cases, when judges are for some reason more acute than normal. On the other hand cases will sometimes occur in which judges are not in their best condition, resulting in correlations which are too low in relation to the standard deviations or in standard deviations which are too high in relation to the level of the correlation coefficients. Variation in judging ability of judges results in correlation between average standard deviation and texture coherence or between average standard deviation and the average relation between texture properties and specific gravity being imperfect.

As to the reasons for differences in the relation, both qualitatively and quantitatively, between specific gravity and texture properties, very little is known.

Undoubtedly conditions during growth of the crop exert a strong influence on this relation. This may be proved by the fact that correlation coefficients between specific gravity and texture properties in the variety

Libertas in 1957 (176 samples) and 1958 (212 samples) from sandy soils were practically indentical, but that the correlation coefficients in 1959 (100 samples) were all much lower, practically nil, with correspondingly lower standard deviations for texture properties but not for specific gravity. The only reason for this must lay in the fact that 1959 was characterized by an extremely dry growing season.

A factor which probably is very important in the case of variety trials is the variety pattern of the field. This may be seen in figure 9 in which the relation between specific gravity and mealiness is shown for several fields (The diagonal lines have been drawn to facilitate a comparison between fields, but have no further meaning). There were 27 varieties in toto but each field contained only a part of them and the composition of this part varied from field to field. So there was only one variety (number 24) present on all six fields, others were present on some fields but missing on others and some

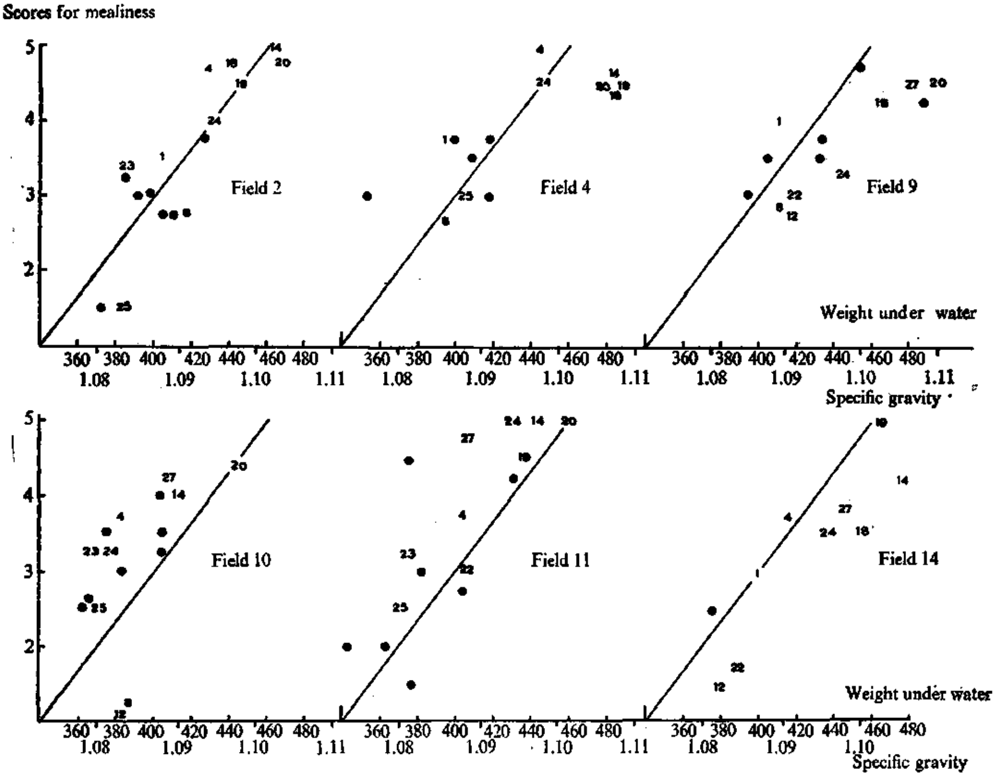

Fig. 9. Relation between specific gravity and scores for mealiness (judged in a scale of 5 points) in variety trials in 1958 (Numbers represent different varieties, diagonal lines serve to facilitate comparisons between fields).

varieties could only be found on one field. Several varieties have been indicated in the graphs by numbers instead of dots, which enables us to study their position in the groups. Thus it may be seen that the varieties 4, 14, 18, 19 and 20 mostly are situated rather close to each other, with number 4 always on the left side of the group and number 20 always on the right side. Furthermore we see that numbers 8 and 12, in spite of practically the same specific gravity, are always less mealy than number 1. The same is true if we compare 25 and 23, etc.

This indicates that the relation between specific gravity and texture properties may vary from variety to variety and that consequently the relation found on a certain field is determined to a considerable extent by the variety pattern of the field.

Assuming that it is indeed starch content which is responsible for texture properties, this would mean that, in view of the variable relation between texture properties and specific gravity under influence of the variety, the relation between starch content and specific gravity is also affected by variety, but, what is more, by growing conditions as well. As this has not been proved it must be assumed that next to starch content other factors are responsible for variety texture. This, however, remains to be solved by chemists, although some speculations could be made.

The conclusion to be drawn from this chapter is, that a relation between specific gravity and texture properties is always present. Where this relation is not shown this must probably be contributed to the fact that variation in texture properties is often too small to show the relations. Moreover, it has been shown that the regression of texture properties on specific gravity varies from field to field, resulting in low standard deviations of texture properties when regression coefficients are low (but nevertheless significant), standard deviations of specific gravity being in practice relatively constant from field to field. Varieties show differences in the relation between texture properties and specific gravity; therefore the variety pattern of a field is one of the causes for differences in the regression of texture properties on specific gravity between fields. Also growing conditions may exert an influence on the relation between texture properties and specific gravity.

Specific gravity, although important, is not the only factor responsible for texture properties.

The most important conclusion in the scope of this thesis is, that specific gravity alone cannot be used as an objective method for measuring texture properties, especially because of the varying relation between specific gravity and texture properties.

5. MATERIAL AND METHODS

5.1. Material

When we selected the potatoes for the initial testing of the planned methods one fact was emphasized, namely that we wanted a range in each texture property which was as great as possible. Our knowledge of the characteristics of many varieties was of course of great help in this respect, but in order to maximize variation the variety samples were also divided into several specific gravity classes and samples of each specific gravity class were cooked and judged.

In this experiment, which we will call "Dutch variety trial 1960", the number of specific gravity classes of each variety varied from 2 to 4, the total number of samples was 29, each being cooked and judged in tenfold. Ten varieties were represented. Specific gravity ranged from 1.050 (weight under water 240 g) to 1.110 (weight under water 495 g), with intervals being 0.010.

We also had at our disposal samples obtained from members of the working group "Potato Quality Research" of the European Association for Potato Research. In this experiment each member sent to each other member one or two samples of potatoes, which he considered as representative for the preference of his fellow-countrymen. In this way samples were obtained which varied greatly in quality properties. Apart from this, the fact that all members cooked and judged the samples according to the same method and the same judgment scale and that this happened at about the same time, meant an important advantage in that methods could be compared not only with our own sensorial results but also with the average opinion of the whole working group, which, as we have seen in chapter 3, is in fact necessary. This experiment will be called the "International variety trial 1960".

In 1961 samples were again obtained from the international working group and we will refer to that experiment as the "International variety trial 1961".

As to the "Dutch variety trial 1961" the working method was modified in the following way. About 320 samples obtained from 14 field trials were cooked and judged three times from October 15 to November 15, after which the samples for testing the methods were selected on the basis of these results. In this way we could select for each quality property those samples which showed maximal differences in the quality property concerned.

5.2. Method of cooking

To get a good insight into texture properties some precautions have to be taken. For instance, when some layers of potatoes are cooked, the upper layer will exert pressure on the lower one, which will result in differences in softness and probably in sloughing. If potatoes are cooked under water the intensity with which the water is boiling will affect sloughing and falling apart. The way in which the potatoes are put down on the plates after cooking may have an influence on falling apart.

To eliminate these undesirable influences the following procedure has invariably been followed. After peeling some 6 to 8 potatoes, depending on the size, very thinly (about 2 mm thick) with a thin-peeling knife and removing the eyes and remainder of the skin, they were steamed while lying in one layer on a grating about 2 cm above the bottom of the pyrex dishes. Special care was taken in choosing potatoes of uniform size (with a weight of preferably about 100 grams), because the time of cooking required is strongly dependent on the dimensions of the tubers.

All dishes received so much water that the level was just below the grating. Salt was not added. Pyrex dishes were used because the beginning of boiling of the water could be observed immediately and the supply of heat could be diminished so that the boiling just continued. Moreover, the process of cooking can be followed very easily in these dishes.

Heat was supplied by electrical cookers with a diameter similar to that of the bottom of the dishes (14.5 cm) and with a maximal output of 1000 W. Twenty of these cookers were at our disposal.

Doneness was judged by pricking with a thin knitting needle and in cases of doubt, namely when we did not know if the resistance during pricking was caused by the fact that potatoes were not done or by the fact that they were very hard though they were indeed done, this problem was solved by using a stethoscope during pricking. In the former case bursting of the cell walls can be heard, in the latter only a slight rustling is observed. When cooking the potatoes under water this method will not fully satisfy, because then a tumultuous noise of the boiling water may drown the sound of the bursting cell walls. After doneness the potatoes were put down on plates as carefully as possible.

5.3. Method of judging

The international working group "Potato Quality Research" of the European Association for Potato Research in its session of February 1958 (LUGT and GOODIJK, 1958) recommended the use of a scale of five points in which each point represented the description of the intensity of a quality property.

With this scale we worked very satisfactorily but the same working group in its session of 1959 decided to reduce the scale to four points (LUGT and GOODIJK, 1959). This decision put us in a difficult position. On the one side we were quite willing to follow the advice of the working group, but we also had to take into consideration that to follow this advice would disturb the investigations we were carrying out, which were to be repeated in the same way for some years. Consequently we decided to follow their advice after finishing the current program, which was after judging the samples of the experimental fields in 1960.

Therefore in the Dutch variety trial 1960 a scale of five points was used, but in the same trial in 1961 this was replaced by the four points scale of the international working group. With respect to the International variety trials of both years the four points scale has of course been used.

About these scales it only need be stated that

1 means: not falling apart	and 5 (or 4): complete falling apart
not sloughing	strong sloughing
not mealy	very mealy
humid	dry
firm	soft
with a fine structure	with a coarse structure

Some particulars about judging, however, should be mentioned. For instance, we do not agree with the opinion of some research workers that best results are obtained if all quality properties of one and the same sample are judged before judging the next sample. In our opinion this system is extremely boring if great numbers of samples must be judged. Moreover, it is time-consuming and does not offer the judges a chance to check on the correctness of their judgment. A shift in interpretation of the scale is then quite possible. The danger also exists that correlations between properties are found which in reality are not present.

In order to keep interest alive and to keep a hold on the correctness of the judgments we prefer to judge several samples together, by which method one and the same property of all samples is judged before judging the next property. The number of samples to be judged together generally varies according to the nature of the experiment but never exceeds twelve at a time. In this investigation, however, in 1960 only five samples were judged at the same time, because the measurement by objective methods concurred with sensory judgment, thus limiting the capacity. In 1961 this concurrence was not maintained and about ten samples were judged each time.

As the samples of the Dutch variety trial in layer will exert pressure on the lower one, which will result in differences in softness and probably in sloughing. If potatoes are cooked under water the intensity with which the water is boiling will affect sloughing and falling apart. The way in which the potatoes are put down on the plates after cooking may have an influence on falling apart.

To eliminate these undesirable influences the following procedure has invariably been followed. After peeling some 6 to 8 potatoes, depending on the size, very thinly (about 2 mm thick) with a thin-peeling knife and removing the eyes and remainder of the skin, they were steamed while lying in one layer on a grating about 2 cm above the bottom of the pyrex dishes. Special care was taken in choosing potatoes of uniform size (with a weight of preferably about 100 grams), because the time of cooking required is strongly dependent on the dimensions of the tubers.

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As the samples of the Dutch variety trial in 1960 were judged in tenfold we thought it advisable to prevent judges getting so accustomed to the samples that a shift in the scale was to be expected. Moreover, we did not want to run the risk of some samples being recognized. Therefore the samples of this experiment were arbitrarily placed between samples of other variety trials in such a way that each replication of the experiment contained samples of other variety trials. Thus the "surroundings" of the samples of the experiment were varied in each replication.

The samples of the remaining variety trials were cooked in the usual way and judged three times with an interval of several days between the various judgments.

Testing of the methods was performed in as many replications as with sensorial judgment.

5.4. Methods for measuring texture properties

As has been shown in chapter 3 some texture properties are so closely related that one could ask whether they are indeed separate properties and not the same property, estimated in different ways. These characteristics are mealiness, dryness and structure. Therefore only one method was needed and this method is based on our knowledge of mealiness.

It has been shown too that softness of the potato seems to occupy a somewhat separate position, which means that for this property a method also had to be designed. At the same time we would try to see if this method would be useful for measuring falling apart.

This leaves one property, namely sloughing, which is related to mealiness as well as to softness. For this characteristic no suitable mechanical method could be devised, but something will still be said about this property in the paragraph concerned.

One property has not yet been mentioned, as it only is of importance in some varieties. This property could be called fibrousness.

5.4.1. *Methods for measuring mealiness*

As has been stated in chapter 1 we understand by mealiness the degree of crumbling of the potatoes after the cooked tubers have been mashed with a fork. Mealy potatoes will then fall apart into small dry cumuluslike crumbs, which show little coherence to each other or to the plate and which display a glistening white surface. By this lack of cohesion a fork can be stirred very easily through the mass. In non-mealy potatoes big lumps with a strong mutual cohesion and a strong adhesion to the plate will from. These lumps show no glistening white but a more or less wet surface. They cannot easily be stirred with a fork.

In 1960 it was tried to find a method by which the resistance could be measured when an object was stirred through the mashed potato, but this was not as simple as it seemed to be (See UNRAU and NYLUND, 1957). In fact it seemed to be simpler to drive mashed potato tissue through an instrument than an instrument though the mashed potato tissue.

Therefore we measured the quantity of potato tissue which during a certain time was pressed with a certain pressure through a hole. For this purpose a plastic cylinder with a length of 20 cm and an inner diameter of 25 mm was used, which was closed at one end with a disk of 4 mm thickness. In the centre of the disk, which fitted with a screwthread in the cylinder, was a hole with a diameter of 4 mm. In the cylinder a piston could be placed which was weighted down with 2500 grams.

It will be understood that this instrument can be made by simple means. In fact it was manufactured by rebuilding an old tyre-inflator, such as is sometimes attached to bicycles, only the hole in the "bottom" had to be made smaller, which was very simple.

Into the cylinder about 25 grams of potato tissue was brought, which was "homogenized" by pressing mashed potatoes, which still contain many lumps, through a sieve with holes of 2 mm diameter. Then some pressure was exerted on the tissue by means of the piston till a "sausage" of two or three centimeters was visible. After discarding this tissue cylinder the weight was released and after exactly one minute the pressure was taken off, and the tissue cylinder produced was weighed.

Some observations were also made about characteristics of the "sausage", namely the glistening, the stickiness and the firmness. This was done by describing these properties in simple terms such as no, little, rather and strong.

On account of our experience with this method it was replaced in 1961 by another. For reasons which will be explained in the next chapter the method of 1960 did not give satisfaction, although the stickiness of the "sausage" proved to be of importance. Therefore another method was based on this principle.

The only thing needed is a simple domestic scale, of which a spring is the essential part (figure 10 and 11). In this type with a range of 2 kg the dial plate is attached in such a way that it can be revolved round the axis on which the needle has been mounted. This has practical advantages.

The principle of this method is that, while the needle is standing on zero, a ball of about 50 gram of potato tissue on the scale is to a certain extent pressed together by a weight which descends with a certain speed. The needle will then show a deviation. At a certain point the weight will be pulled up

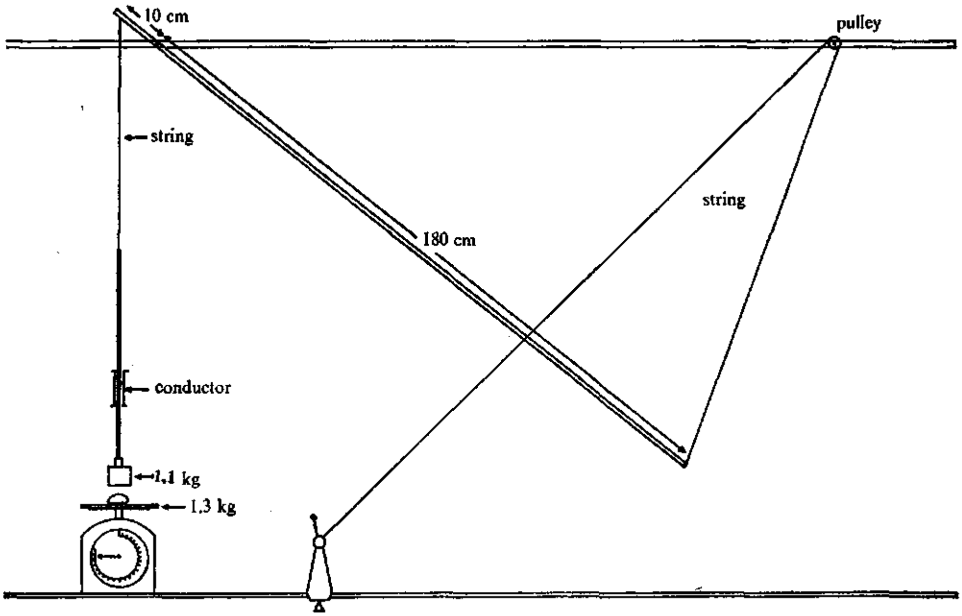

Fig. 10. Instrument for measuring mealiness of cooked potatoes.

with the same speed. During this pulling up the needle will pass the zero point, but owing to the adhesive force of the potato tissue the needle will be pulled further and will fall back to zero when the adhesive force of the tissue is overcome by gravitation.

It will be clear that the normal zero point cannot be used and therefore a metal plate of about 1.3 kg was placed between the scale and the potato tissue. The needle will consequently point to the left and this point is used as zero. As reading in this way may give rise to errors the part of the dial plate concerned was provided with another scale on which the adhesive force of the potato tissue could be read directly in 25 grams.

It is essential for this method that descending and ascending of the weight is very constant. Of course this can be done best by a motor, but, not knowing the merits of the whole system, this seemed to us premature and consequently descending and ascending of the weight was done by hand.

In figure 10 it can be seen that the practical solution for this problem is very simple. As our experience was that, in order to obtain a rather constant speed without fits and starts, a certain minimum speed is required of the man turning the handle of the axis on which the string is wound, we needed a transmission by which the high speed of the turning handle was changed into a low speed of the descending or ascending weight. This was obtained by a construction by which the transmission in linear speed was about 18 : 1. As the diameter of the axis was about 14 mm and the axis made 80 rotations per minute the speed of descending and ascending was 3.3 mm per second, which was maintained very well, as measurements proved.

The adhesive force is of course dependent on the nature and the area of the weight pressing on the tissue. Therefore a circular smooth metal plate with a diameter of 6 cm was attached to the bottom of the weight. Actually the lid of a round tin box was used.

The procedure is as follows. Potatoes are mashed with a fork and pressed through a grater with holes of 2 mm diameter (For the latter operation suitable domestic graters are on the market). Next, about 50 grams of tissue are carefully kneaded into a ball, which is put down on the metal plate lying on the scale, after which the needle is brought in zero position by shifting the dial. The weight is let down with a speed of 3.3. mm per second till the string to which the weight is attached just begins to lose its tension owing to the fact that the needle is stopped at about 45° beyond the vertical position. Turning of the handle is then immediately stopped during 3 seconds and then the weight is pulled up with the same speed. The adhesive force is read just before the needle falls back to zero.

Assuming that for each man the "natural speed of rotation" will slightly differ, the transmission has to be chosen in such a way that the speed of 3.3 mm/sec is obtained if the man who handles the winch turns with his "natural" speed.

5.4.2. *Methods for measuring softness*

In 1960 a method was used by which a rod of a certain weight fell from a certain height on the cooked potato, after which the distance the rod penetrated into the tuber was measured. Figures 12, 13 and 14 give pictures of the instrument.

Neither the dimension of this instrument nor the material used are of any importance if only three points are accounted for, namely that the rod which is moving in the cylinder has a weight of 175 grams and a diameter of 12 mm (see figure 12), that the height of falling is 20 cm and that the fall happens with very little friction. The place of the scale which is divided into millimeters is determined by the place of the pin, which is conducted by the slit in the cylinder. The position of the pin namely is read for measuring the penetration. Consequently the position of the pin is zero when the rod is standing

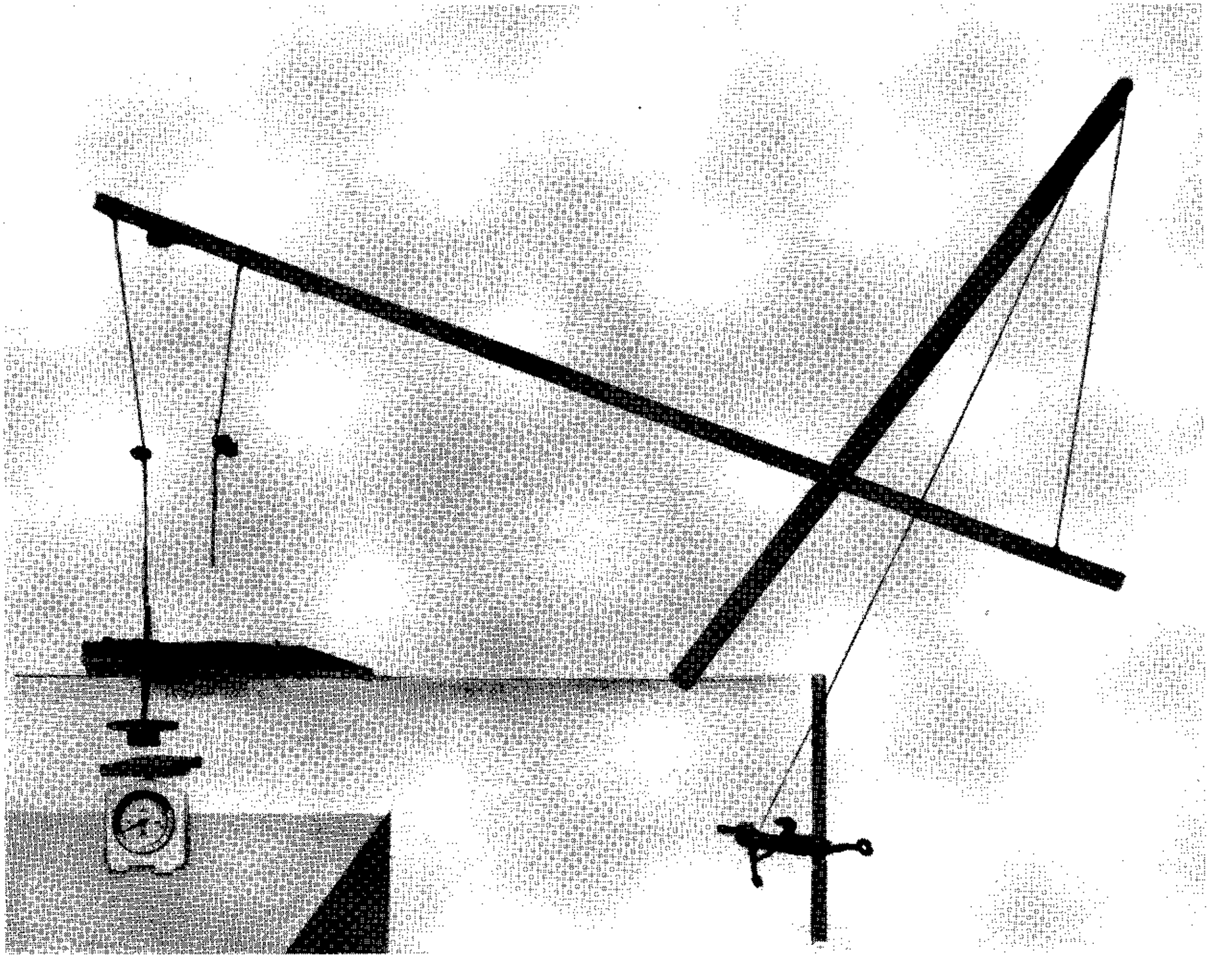

Fig. 11. Instrument for measuring mealiness of cooked potatoes.

(Photograph by Mr. J. H. Rutgers. Office of Joint Services, Wageningen).

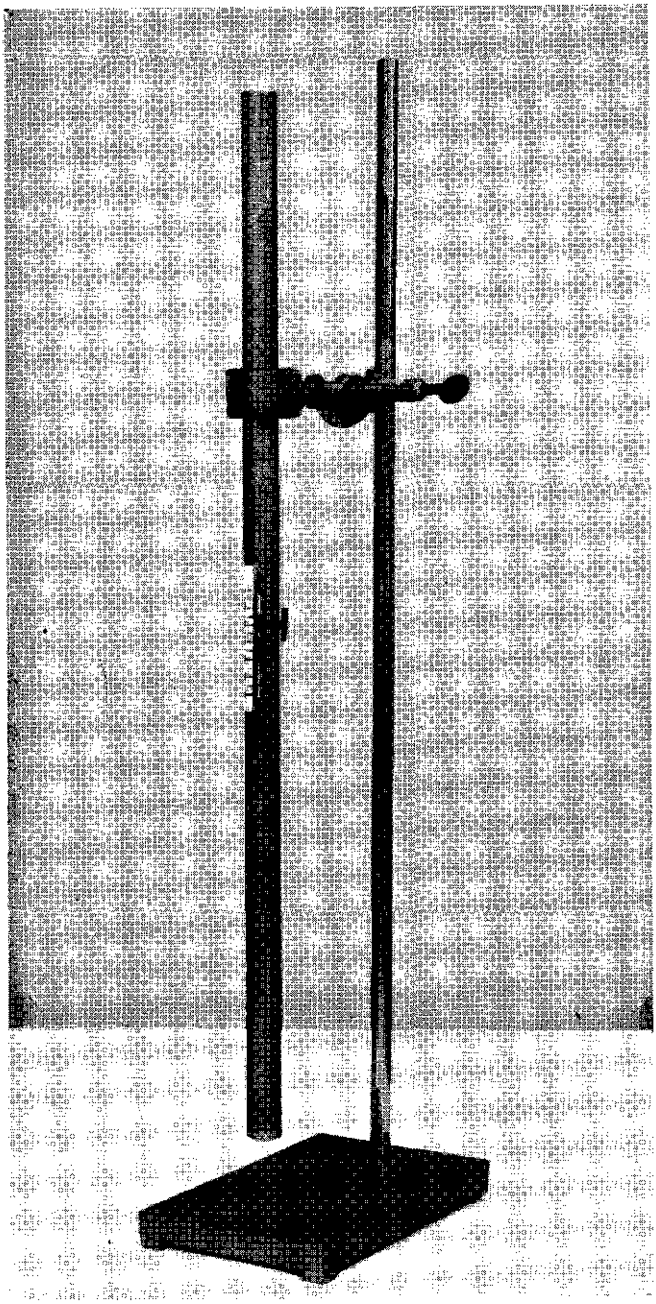

Fig. 13. Instrument for measuring softness of cooked potatoes.

(Photograph by Mr. J. H. Rutgers, Office of Joint Services, Wageningen).

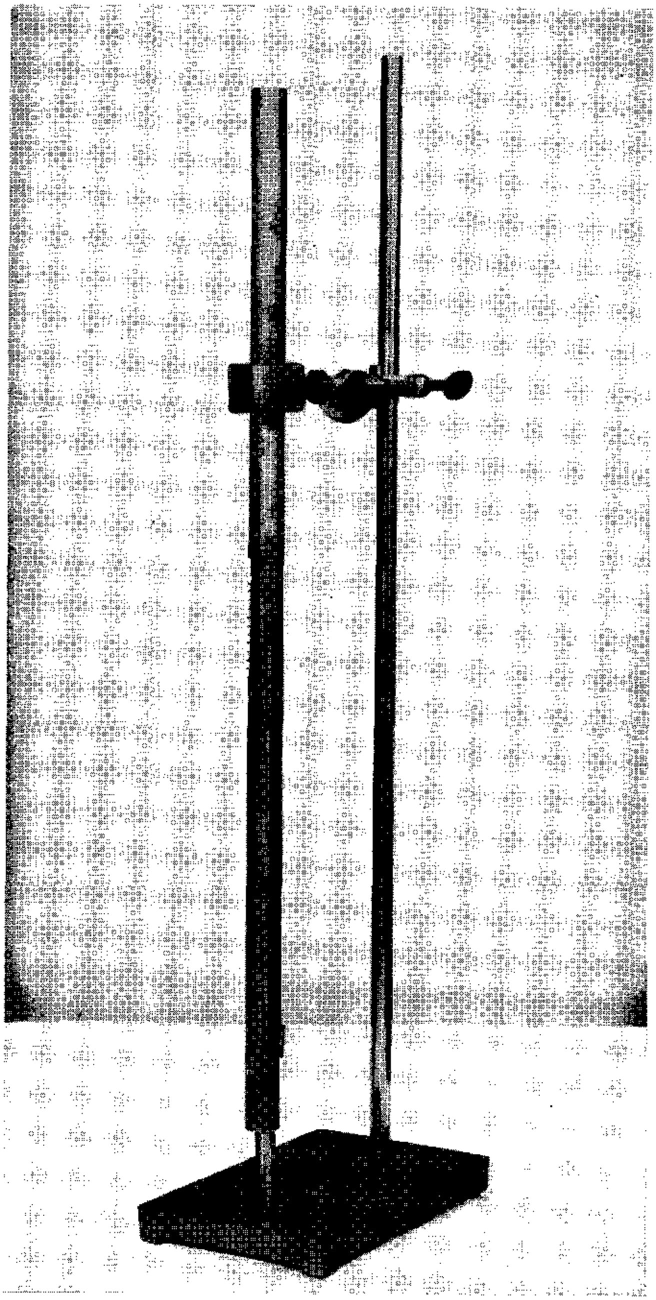

Fig. 14. Instrument for measuring softness of cooked potatoes.

(Photograph by Mr. J. H. Rutgers, Office of Joint Services, Wageningen).

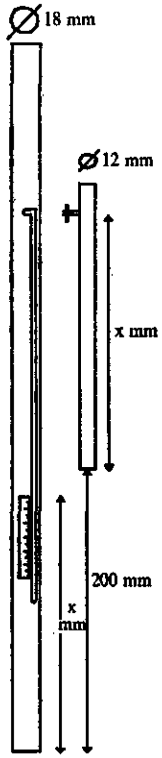

Fig. 12. Instrument for measuring softness of cooked potatoes.

on the potato without penetrating it. In the beginning of these experiments instead of the pin the upper end of the rod was used for reading off penetration (fig. 13 and 14) but this was not very satisfactory, because visibility was lacking.

To clean the instrument the pin, which is attached to the rod by screw-thread, is removed, but if the cylinder is made of sufficiently strong material the slit may be extended to one of the ends of the cylinder so that the rod may be removed without removing the pin, and no screwthread is needed.

It will be clear that the lower end of the cylinder is placed on a potato without pressing it and the rod is released by a touch against the pin which is supported by the horizontal part of the slit.

In 1961 apart from this method another one was tested, which made use of the mealiness measuring device of that year. In figures 15 and 16 the

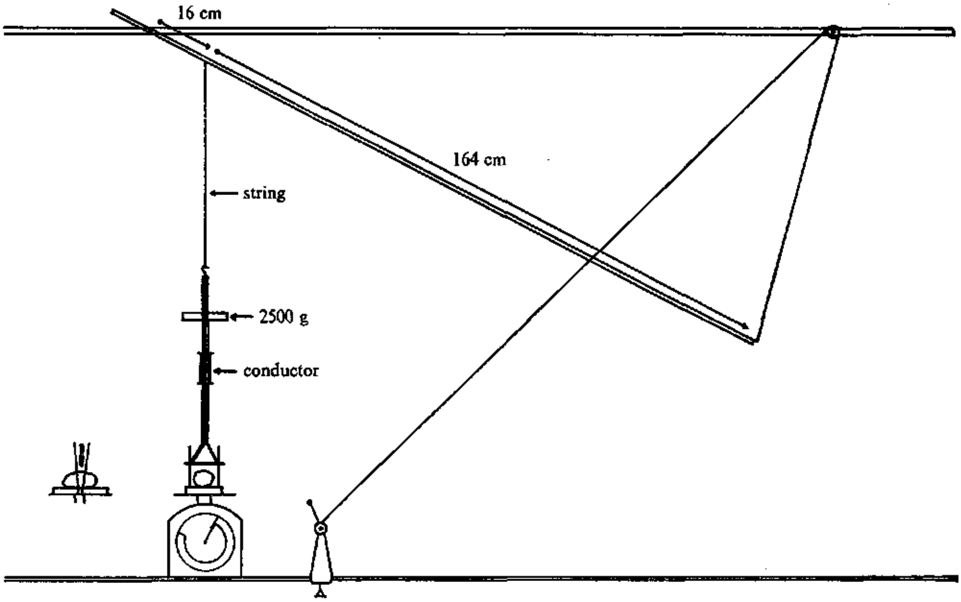

Fig. 15. Instrument for measuring softness of cooked potatoes.

instrument can be seen. As with the measurement of stickiness a constant speed is again essential.

The principle is the force needed to press a rod with a certain speed transversally through the cooked potato.

This rod in the form of a triangle has a diameter of 2 mm and a horizontal length of 8 cm as this must be longer than the largest transversal diameter of any potato. The weight is 2500 grams but this is of secondary importance as long as the weight is sufficient for the string to keep its tension. The speed of the descending rod is 4.5 mm/sec at 80 rotations per minute of the handle. To prevent misreadings the distance between the ring supporting the weight and the upper end of the conductor is chosen so that the rod can not touch the scale. Moreover, the potato is lying on a piece of wood with a slit in it in which the rod is conducted. Figure 16 gives the original version in which, moreover, a much thicker rod was used.

After putting down the potato on the scale the dial plate is moved with its zero point to the needle, the rod is let down with the required speed and two positions of the needle are read, namely the maximal position just before the rod penetrates the outer layer of the potato and the average position when the rod is passing the centre of the tuber.

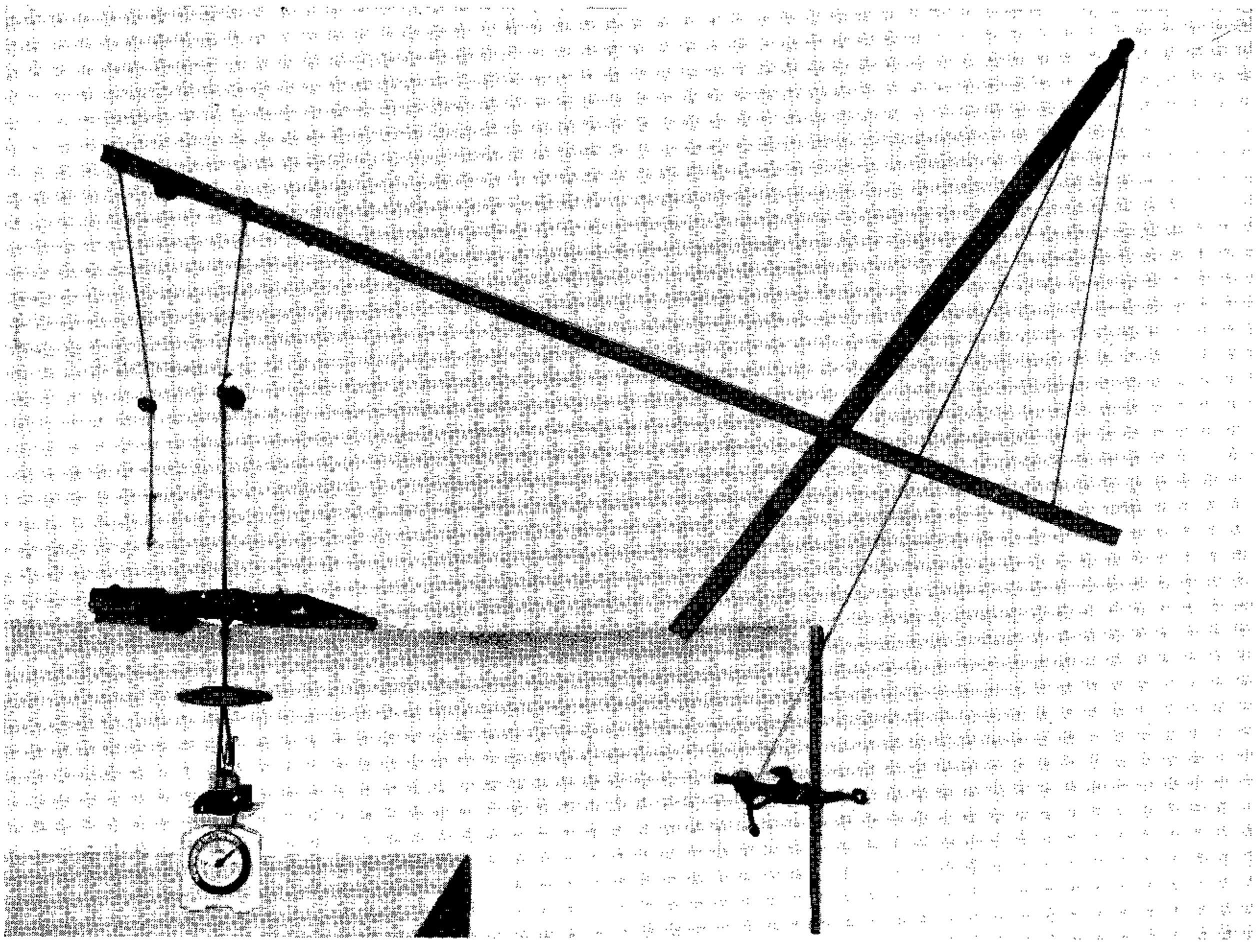

Fig. 16. Instrument for measuring softness of cooked potatoes.

(Photograph by Mr. J. H. Rutgers, Office of Joint Services, Wageningen).

Sometimes potatoes were halved and one half was measured with its cut surface upward and the other half with the cut surface downward.

It should also be remarked that the triangle was occasionally replaced by a vertical rod which, with the inclusion of the added weight, had a weight of 1 kg and a diameter of 8 mm.

5.4.3. *Method for estimating fibrousness*

In some varieties an excessive degree of fibrousness is observed which, as we remarked earlier, would not be appreciated by consumers. This is a typical variety characteristic, as all Dutch varieties which show this phenomenon are related to each other.

This fibrousness is not caused by fibres in the botanical sense but by the xylem, which can be shown by the red colour originating when phloroglucinol and hydrochloric acid are added. On this colour reaction the method is based.

After cooking the potatoes the stem ends (about 10–15 grams in weight) are cut from the tubers and mashed with a fork. About 20 grams are weighed roughly, put down in Petri dishes and covered with 20 ml of a solution of 0.5 % phloroglucinol in 25 % HCl (As this solution shows a red colour after a short time it cannot be stored too long and if occasionally some samples have to be treated it is better to store phloroglucinol and HCl separately and add them separately. Phloroglucinol in that case is best dissolved in aethanol).

Length of the red "fibres" is estimated in millimeters, while for the thickness adjectives are used such as very thin, thin, rather thick, etc. The degree of sheaf formation is estimated as well, also in subjective terms. The number of fibres is not counted.

6. RESULTS CONCERNING TEXTURE PROPERTIES

6.1. Results with the methods for measuring mealiness

1960. Preliminary investigations with some samples pointed to a reasonable relation between mealiness and the quantity of potato tissue pressed in one minute through the hole. Also the Dutch variety trial gave at first sight a good correlation, namely of −0.738. However, the correlation between mealiness and specific gravity proved to be considerably higher, namely 0.936. This means that in this experiment specific gravity obviously was a better measure than the quantity of tissue pressed through the hole. The regression equation of mealiness, expressed in a scale of four points, on weight under water was: mealiness = 0.0127 × w.u.w. — 1.92. It is evident that the whole scale has been used with this material, because for a mealiness of one (not mealy) a weight under water was needed of 231 (s.g. 1.0484), while the lowest specific gravity was in fact about 240. In general a one for mealiness is obtained at a much higher specific gravity, as can be seen in figure 17. On the other hand the maximum mealiness was obtained at normal specific gravity (466 g).

As a calculation of the multiple correlation coefficient showed that the gain in information was not significant when considering the quantity of tissue pressed through the hole as supplementary to specific gravity, it seems probable that the former characteristic must be considered a rough measurement of specific gravity. Apart from this the method also gave little satisfaction as some samples showed an enormous variation in the results. One sample, for instance, showed values varying from 251 to 1680 grams per minute, which means that in a few seconds the whole quantity of tissue was pressed through, while in samples of other varieties in one minute only 5 grams were pressed through.

One of the causes of variation could lie in the difference in values between tissue of the centre and tissue of the outer layers of the potatoes. In the first case figures are much higher. Therefore sampling must be done very carefully, but in spite of this in some samples a constant figure could not be obtained.

The results of this method with the samples of the International variety trial in 1960 were still worse than with the samples of the Dutch variety trial. In this case the correlation coefficient between mealiness and specific gravity was 0.725, but between mealiness and "sausage production" no correlation coefficient has been calculated, in the first place because variation in results of the samples was again considerable and in the second place because dot charts showed that this correlation was negligible.

Nevertheless this method offered some interesting prospects, namely when the appearance of the produced cylinder of potato tissue was observed. At first sight strong differences could be observed between samples of the Dutch variety trial. The cylinders of mealy potatoes seemed to show less glistening and less stickiness when pressed with a finger than the cylinders of less mealy potatoes, and besides they were firmer but more fragile than the latter, which showed more coherence and weakness and often a certain toughness.

As has been said these appearance properties of the tissue have been judged in terms as no, little, rather, strong and very strong stickiness, etc. By attributing to these adjectives the figures 1 to 5 correlation coefficients could be calculated between these properties and mealiness. These coefficients amounted in the order glistening, stickiness and firmness of the tissue cylinder to −0.919, −0.893 and 0.948 respectively for the Dutch variety trial. Moreover, if these properties were implicated in the correlation coefficient between specific gravity and mealiness by computing the multiple correlation coefficient between mealiness on the one hand and specific gravity and one of the three mentioned properties on the other, this coefficient was about 0.97. The increase in comparison with the correlation coefficient between specific gravity and mealiness, which was 0.936, appeared to be significant. A certain gain in information may consequently be noted.

Working in the same way with the samples of the International variety trial in 1960 the correlation coefficient between specific gravity and our figures of mealiness was 0.725. Glistening, stickiness and firmness of the tissue cylinders gave correlation coefficients with mealiness of −0.730, −0.762 and 0.542. Although in these experiments correlation coefficients were considerably lower than in the Dutch variety trial in 1960, yet the judgment of the tissue cylinders yielded profit because the multiple correlation coefficient between mealiness on the one side and specific gravity and one of these properties on the other amounted to 0.849, 0.879 and 0.809 respectively.

It may be asked which result would be obtained if our figures were replaced by the average figures of the working group, the latter being considered "more correct" than the former. It appears that the correlation coefficient between specific gravity and mealiness was 0.684, between mealiness and glistening, stickiness, and firmness −0.666, −0.703 and 0.390 respectively. The multiple correlation coefficients in the same order were 0.787, 0.820 and 0.716. The "gain" was not significant in the case of firmness.

In the International variety trial the regression line of our mealiness figures on weight under water fulfills the formula: mealiness = 0.0172 × w.u.w. − 4.27 (see fig. 17).

Of the working group the regression of the average results for mealiness on weight under water was: mealiness = 0.0125 × w.u.w. − 2.73. This means that this line runs more horizontal and shows a lower level than our judgment.

It should be remarked that the standard deviation of the regression coefficient was in both cases highly significant.

When comparing these formulas with the formula of the Dutch variety trial it appears that the level of the line of the Dutch variety trial shows a better agreement with the line of our judgment of the international samples than with the line the average judgment of the working group, but that the slope of the line of the Dutch variety trial agrees better with the slope of the line of the average judgment of the working group than with the slope of the line of our judgment.

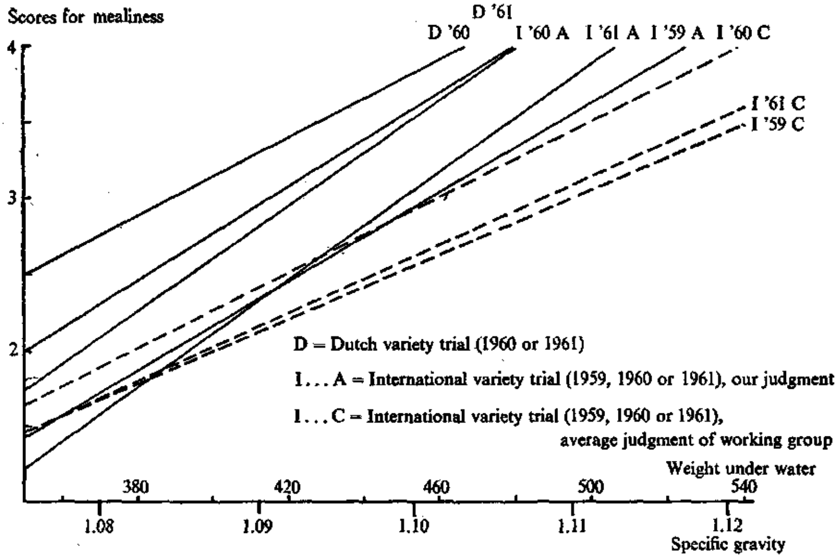

Fig. 17. Regression of scores for mealiness (judged in a scale of 4 points) on specific gravity (weight under water).

That the correlation coefficients of the International variety trial show such great differences with the correlation coefficients of the Dutch variety trial must be contributed to three facts, viz. in the first place to a difference in variety pattern, in the second place to the fact that the latter trial was cooked and judged ten times, whereas the former trial only three times, and finally to the greater range of the latter trial. Especially the last mentioned factor is responsible because if we limit the specific gravity range of the Dutch variety trial to the same range as shown by the International variety trial, the correlation coefficient between mealiness and specific gravity decreases from 0.936 to 0.639.

1961. During the experiments in devising a method based on firmness of a cylinder of tissue the most interesting samples disappeared gradually from our collection. When it became evident that stickiness of the tissue could be measured better than firmness of a cylinder of tissue, many samples had to be used again to elaborate a method. Therefore in the ultimate testing of the method devised the most interesting samples had disappeared and we had to be content with a number of samples of a variety trial which arrived at the laboratory at the moment the method was ready for testing. Nevertheless some interesting results were obtained.

The correlation coefficient between mealiness and specific gravity was 0.749 and between mealiness and stickiness −0.770. The multiple correlation coefficient was 0.825. The increase in the multiple correlation coefficient compared with the two first mentioned figures was significant.

The regression equations were:

mealiness = 0.0153 × w.u.w. − 3.35

and mealiness = −0.5568 × stickiness + 4.70.

The multiple regression equation was:

mealiness = 0.0070 × w.u.w. − 0.2907 × stickiness + 0.9941.

After a discussion of the results with the International variety trial we will return to these results.

The International variety trial 1961 gave the following results. The correlation coefficient between mealiness and specific gravity was 0.716 and between mealiness and stickiness −0.902. A calculation of the multiple regression coefficient showed no favourable influence of specific gravity as a supplement to stickiness.

However, one remark should be made. Three samples showed some deviations in the relation between mealiness and specific gravity, as well as in the relation between mealiness and stickiness. The reasons for the deviations of two of these samples are undoubtedly that these samples were received a considerable time after the remaining samples had been cooked and judged. So they had to be cooked and judged separately from the remaining samples so that a shifting in interpretation of the scale may have occurred. The third sample deviated more markedly, because its mealiness was far too low in comparison with specific gravity and stickiness. The reason for this is probably that this variety was very firm and therefore mealiness has been underestimated.

Recalculation of the coefficients showed figures of 0.745 and −0.960 as compared with 0.716 and −0.902.

On level and slope of the regression lines, however, this omission of results had no appreciable effect. The regression lines fulfill the equations

mealiness = 0.0178 × w.u.w. − 5.01

and mealiness = −0.6768 × stickiness + 5.22.

In this relation it is important to note that the regression line of mealiness on specific gravity of the Dutch variety trial in 1961 is situated on a much higher level than the line of the International variety trial in 1961. The regression lines of mealiness on stickiness, however, are in both cases nearly identical (see figure 17 and 18), although the correlation coefficient in the Dutch variety trial was much lower. Nevertheless it seems, that the judgment

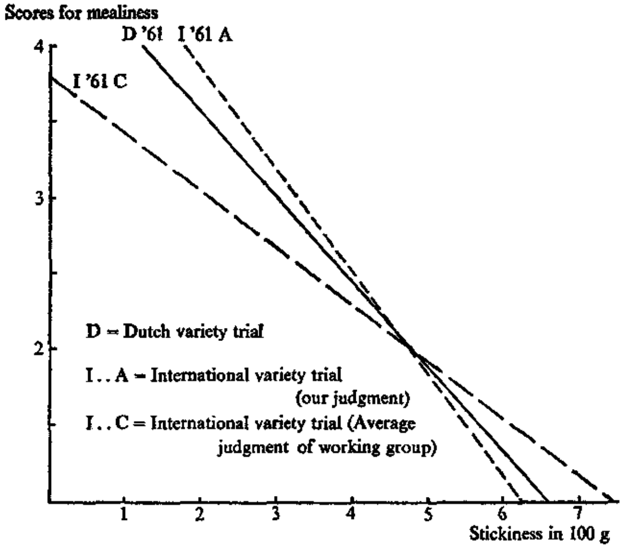

Fig. 18. Regression of scores for mealiness of whole potatoes (judged in a scale of 4 points) on stickiness of a cylinder of cooked tissue.

of this trial was essentially the same as that of the samples of the International variety trial.

It may be remarked that fig. 17 gives a clear picture of the variation in the quantitative relation between mealiness and specific gravity.

At first sight it could be concluded from the average results of the working group that stickiness and specific gravity gave less indication for mealiness because the correlation coefficients between mealiness and respectively specific gravity and stickiness were 0.727 and −0.773. It is interesting to note that also in this case the three above-mentioned varieties occupied somewhat separate positions. When these samples were omitted, correlation coefficients were 0.796 and −0.879.

Regression equations were

mealiness = 0.0114 × w.u.w. − 2.54

and mealiness = −0.3708 × stickiness + 3.78.

This seems to differ considerably from the equations as established on our judgment, but as this difference is mainly one of slope an explanation is easy. The cause for this is mainly that at both ends of the scale deviations in one direction cannot be compensated for by deviations in the other direction. This means that mealiness averaged over the working group in the "low" end of the scale is slightly too high and on the "high" end of the scale slightly too low.

As in the case of our judgment, specific gravity as a supplement to stickiness could not raise the correlation coefficient with mealiness.

It was somewhat disappointing that correlation coefficients between average judgment of the working group and specific gravity and stickiness respectively were not higher than between our judgment and these characteristics. This may partly be due to the fact that we have assumed that specific gravity and stickiness, as established with our samples, were representative for all samples. The second reason may be that the average of the working group is not at all the best approximation to the "real" mealiness. This is indicated by the fact that correlation coefficients between separate stations and the average of the whole group varied from 0.60 to 0.90.

Therefore a recalculation has been performed with the figures for mealiness averaged over the four stations which gave the best correlation with the average judgments. The correlation coefficients of the results of these stations with the average of the working group varied from 0.82 to 0.90.

Correlation coefficient between specific gravity and the mealiness figures, averaged over these four stations, was 0.797 and between stickiness and mealiness −0.845. Although these correlation coefficients are higher than the correlation coefficients based on the whole working group the regression equations hardly undergo any change. A calculation of the multiple correlation coefficient, however, shows that specific gravity as well as stickiness contribute significantly. This multiple correlation coefficient was 0.894. The regression equation proved to be

$$\text{mealiness} = 0.0069 \times \text{w.u.w.} - 0.2630 \times \text{stickiness} + 0.3960.$$

The resemblance with the equation calculated in the case of the Dutch variety trial is striking with the exception of the constant factor, which causes a difference in level of the calculated mealiness figures. This, however, is caused by the fact that one of the four stations showed a much lower level in mealiness figures than the remaining stations, although correlation coefficient with the average judgment was very high.

In order to test the value of this equation the correlation coefficient was calculated between figures computed from this equation and the real mealiness figures obtained by our judgment. The correlation coefficient proved to be 0.888 which was hardly lower than the correlation as calculated from stickiness according to the equation mealiness $= -0.6768 \times$ stickiness $+$ $+\ 5.22$, which was 0.902. Also the correlation coefficient between figures obtained by calculation and the average figures of the whole working group was satisfactory, as this correlation (0.826) was higher than the correlation coefficients of six of the ten stations.

6.2. Results with the methods for measuring softness and falling apart

1960. During the investigations of the samples of the Dutch variety trial with the falling metal rod it appeared that three different cases could occur:

a. The tuber remains intact and the rod penetrates to some extent.

b. The tuber shows a small rupture on either side of the rod which mostly will penetrate deeper than in the first case.

c. The potato falls apart into two or more pieces.

In cases *a* and *b* the number of millimeters of penetration is noted, but in case *c* this is fixed arbitrarily on 30 mm, so as to eliminate influence of tuber size. Also of each sample the number of tubers is noted which show ruptures or which have fallen apart.

Although at first it was thought that softness would show a rather clear relation with specific gravity, this was neither the case in the Dutch variety trial nor in the International variety trial, as correlation coefficients were 0.575 and 0.320 respectively. The latter coefficient is strongly influenced by two deviating samples. An omission of these samples gave a correlation coefficient of 0.549 which agrees very well with the results of the Dutch variety trial. These correlation coefficients, however, do not give a clear picture of the relation as softness seems to react curvilinearly on specific gravity. This can be seen in figure 19, in which the dots representing the same variety are connected with each other. At the same time it is obvious that the influence of variety on the relation between softness and specific gravity is considerable. Therefore specific gravity will play a minor part when samples of different varieties are compared and consequently will not be a good measure for softness.

Correlation coefficients between sensorial judgment and the aforesaid method were satisfactory as far as the Dutch variety trial was concerned. These correlation coefficients between on the one hand softness and on the other penetration depth, percentage tubers showing a rupture and percentage tubers which fell apart were 0.890, 0.854 and 0.917. A significant increase to 0.932 was obtained if the multiple correlation coefficient was calculated between softness on the one side and penetration and percentage tubers which fell apart on the other.

The International variety, however, showed less favourable results, as the correlation coefficient between softness and penetration was 0.645 and between softness and percentage tubers showing a rupture 0.575. Falling apart caused by the rod rarely occurred.

For this discrepancy the following explanation may be given. An important

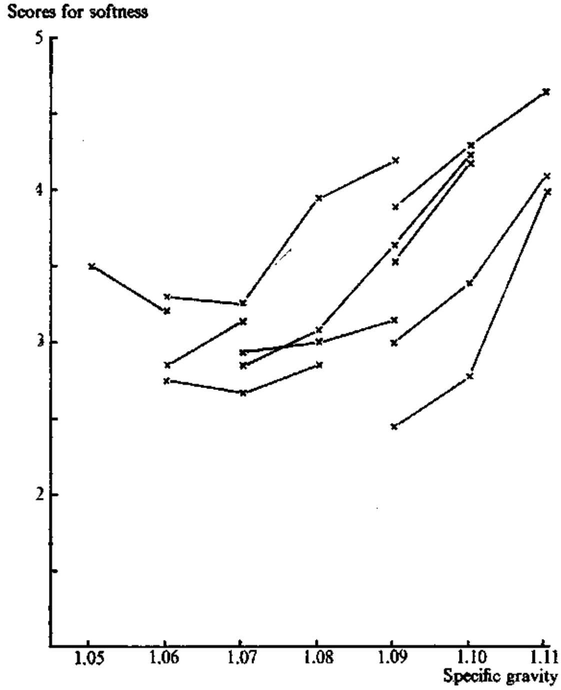

Fig. 19. Relation between scores for softness (judged in a scale of 5 points) and specific gravity. (Dutch variety trial 1960).

difference between both trials was that the Dutch variety trial was performed in tenfold, but the International trial in threefold. That this caused a great difference is shown by the fact that the correlation coefficients between softness and penetration and between softness and percentage tubers with a rupture decreased to 0.699 and 0.655 respectively when these coefficients of the Dutch variety trial were calculated with the data of the first three replications of judgment and measurement. This agrees well with the International variety trial.

Evidently a considerable number of potatoes is needed to measure softness with a certain correctness, but, apart from this, the number of tubers must be divided over a number of replications in order to neutralize the influence of differences in length of cooking time. However this should not be considered a disadvantage of the method, because not the method but the difference in softness between potatoes is the cause of this. This is proved by the rather low correlation coefficients between "station scores" and the average score of the international working group. Therefore probably no other method will give better results.

As for falling apart, which is of special interest for countries where mealy potatoes are favoured as e.g. Ireland and the Netherlands, the methods also gave good results as far as the Dutch variety trial was concerned. (As falling apart did not occur in the samples of the International variety trial this experiment produced no information).

Before going into this, something may be said about the relation between falling apart and specific gravity in the Dutch variety trial. It appears that falling apart plays a role only if specific gravity increases to 1.090 (w.u.w. 410) or higher. This may be concluded from figure 20, but it is evident that also variety influence is very clear.

The correlation coefficient calculated between specific gravity and falling apart for the samples with a specific gravity of 1.080 and higher proved to be 0.691, consequently too low to have any predictive value. The correlation coefficients between falling apart and respectively penetration, percentage tubers with a rupture and percentage tubers which fell apart (either during

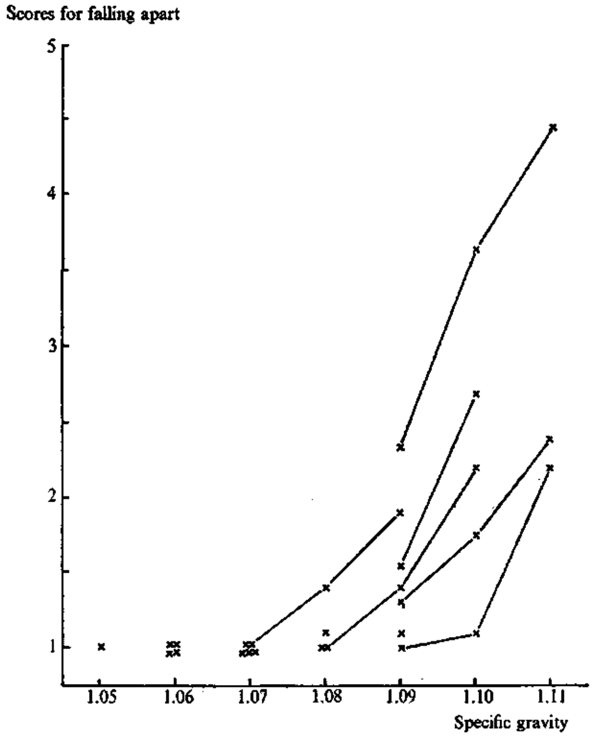

Fig. 20. Relation between scores for falling apart (judged in a scale of 5 points) and specific gravity. (Dutch variety trial 1960).

cooking or under influence of the rod) were 0.764, 0.758 and 0.897. The latter coefficient is clearly higher than the other figures and the level of this coefficient is such that the percentage of tubers which fell apart give a good indication of the susceptibility of potatoes to falling apart. It may be expected that the falling rod exerts an influence comparable with the domestic practice as is customary for instance in the Netherlands, namely cooking under water of more than one layer of potatoes and a rather rough treatment during pouring off and steaming dry.

1961. As the method with the falling rod proved unsatisfactory in the International variety trial of 1960, in addition to this another method has been devised, namely an estimation of the resistance experienced when a metal bar is driven with a constant speed lengthwise or transversally through the potato.

A preliminary investigation of 10 samples was performed in which a bar with a thickness of 2 mm was driven transversally through lengthwise halved potatoes, one half of which was lying with the cut surface down and the other with the cut surface up. Correlation coefficient with softness was in the former case −0.697 and in the latter −0.892. This correlation coefficient was obtained with selected samples which varied considerably in softness. As, in spite of this variation, differences in resistance value were very small it could be expected that results with other samples would show less favourable results. In fact the International variety trial gave correlation coefficients of −0.440 (our judgment) and −0.476 (average of working group).

Therefore instead of driving a bar transversally through the tubers – with the additional drawback that figures had to be corrected for tuber size – in the Dutch variety trial a bar was driven lengthwise through the whole tuber. This experiment was repeated three times, which gave some interesting results. For instance, the correlation coefficients between softness (as judged) of the first replication and the softness of the second and third were 0.663 and 0.477, while the correlation coefficient between the second and the third was 0.601. This is rather low and it may be asked whether this is caused by the judges or by the potatoes. The correlation coefficients between measurements however, were in the same order 0.615, 0.428 and 0.594. This points clearly to the probability that softness of the potatoes of the different series varied, either because of differences between tubers or because of differences caused by varying duration of cooking. The correlation between measurement and judgment in two of the three series was satisfactory namely −0.902 and −0.892, but in the third a bit lower: −0.780. The correlation coefficient based on the average figures of the three replications was −0.881. However, the International variety trial, although cooked, judged and measured in threefold, brought a disappointment, as the correlation between judgment and measurement was −0.441. The correlation between measurement and average figures of the working group was −0.385.

As the regression equation for the Dutch variety trial was

softness = −0.3853 × resistance estimation + 5.22, the regression equation for the International variety trial, based on our judgment,

softness = − 0.4766 × resistance estimation + 5.18 is rather satisfactory, which cannot be said of the equation, based on the average of the working group:

softness = −0.2364 × resistance estimation + 3.50. (See figure 21).

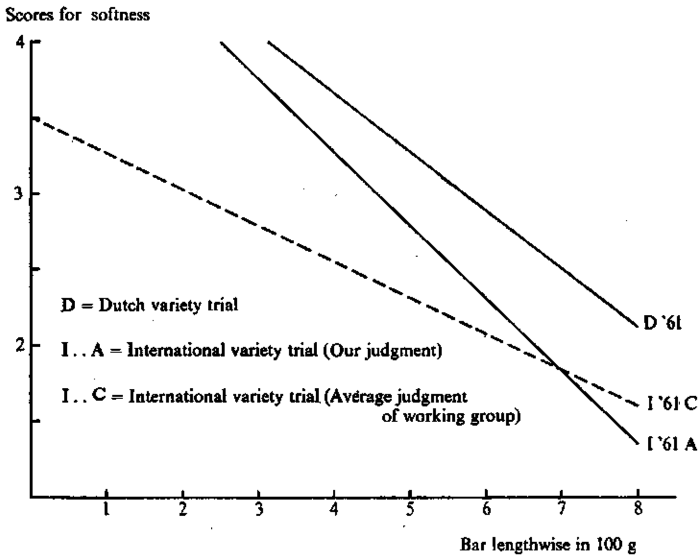

Fig. 21. Regression of scores for softness (judged in a scale of 4 points) on results of measurement of softness.

As in the preceding year, the measure of penetration of the falling rod was tested as a third method for the International variety trial. Unfortunately, again results were not as was expected, correlation coefficients being 0.571 (our judgment) and 0.488 (average of working group). This means that results were somewhat worse than in 1960. Nevertheless a surprising fact emerged when regression equations were calculated, which was done to get an idea how much the different lines would diverge. The regression equations were as follows:

Dutch variety trial 1960	softness = 0.0772 × mm penetration + 1.24	
Intern. variety trial 1960 (our judgment)	,, = 0.0895 × ,, + 1.35	
Intern. variety trial 1960 (av. working group)	,, = 0.0568 × ,, + 1.48	
Intern. variety trial 1961 (our judgment)	,, = 0.0773 × ,, + 1.25	
Intern. variety trial 1961 (av. working group)	,, = 0.0376 × ,, + 1.56	

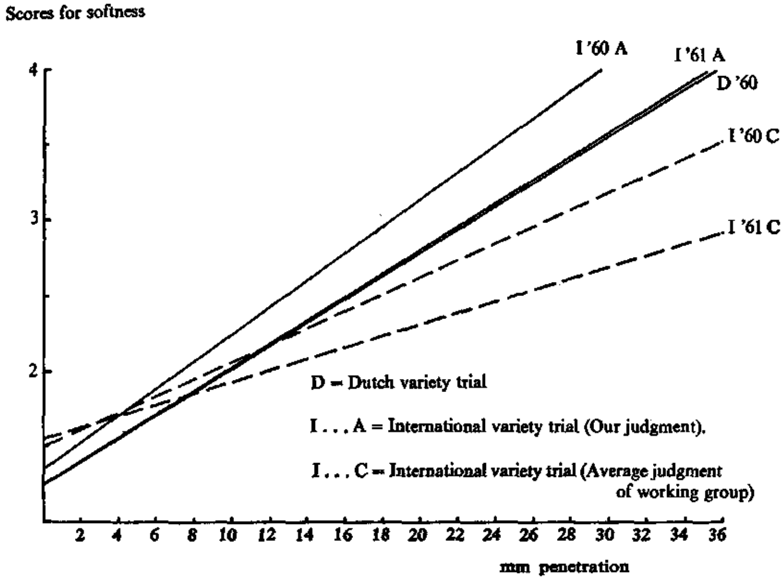

Fig. 22. Regression of scores for softness (judged in a scale of 4 points) on results of measurement of softness.

Figure 22 also gives an impression of these equations. The surprising fact is that the lines of the Dutch variety trial in 1960 and the International variety trial in 1961 (our judgment) practically coincide, although correlation coefficients differed much (Dutch variety trial 0.89, International variety trial 0.57). The slope of the International variety trial in 1960 (our judgment) is somewhat too steep, the lines based on the average judgments of the working group are too horizontal. Especially the line of the average judgment of the working group in 1961 deviates clearly. A „3" for softness is in this case obtained at a penetration of about 40 mm which is improbable.

As a cause for the disappointing level of correlation coefficients of the

International variety trial in both years may be put forward that softness varied too little and that the samples were too small to measure a sufficient amount of tubers. A drawback of softness estimation next to the variation between tubers is that each tuber can be judged or measured only once.

6.3. Some remarks about sloughing

As has been mentioned before, no mechanical method could be devised for measuring sloughing. Nevertheless in this stage of knowledge possibly a measurement could be advised but it would be a chemical method, which is not as attractive as a mechanical method because the former is more labour consuming.

CULLEN (1960) describes sloughing as "the condition where the outer layers of the cooked potato break away from the inner layers. The zone of breakage is almost always in the region of the vascular tissue where the peak of the dry matter gradient occurs. The cooked tissues in this region are usually more floury than those in the outer cortical layers or in the pith" (See also the paper of SHARMA a.o., 1958). He expresses as his opinion that the radial gradient in dry matter content is responsible for sloughing, rather than dry matter content of the whole potato. He illustrates this by the fact that of two new varieties which normally show a similar percentage of dry matter in the whole tuber when grown under similar conditions, tubers of the one variety commonly showed severe sloughing, while those of the other variety remained intact, although tubers of the same specific gravity were compared. In the tubers of the former variety the peak in dry matter content in the vascular region is much higher than in the tubers of the latter variety. He also mentions that sloughing will occur only when percentage dry matter of the whole tuber exceeds 20 %.

That dry matter content or specific gravity plays an important part is illustrated by figure 23 in which tubers are shown obtained by grading potatoes in specific gravity groups with the help of brine solutions. Specific gravity of these tubers which were peeled and halved before steaming were from left to right 1.080 (w.u.w. 370), 1.090 (w.u.w. 415), 1.100 (w.u.w. 455), 1.110 (w.u.w. 495) and 1.120 (w.u.w. 535). It is obvious that in this case sloughing is beginning to occur when specific gravity is 1.100 (w.uw. 455). However, generally speaking it may be assumed that sloughing will seldom occur when specific gravity is lower than about 1.090 (w.u.w. ± 410), unless we have to do with exceptional varieties, such as mentioned in chapter 3.

In the lower row of the potatoes in figure 23 the increase in starch content in the vascular region is clearly visible.

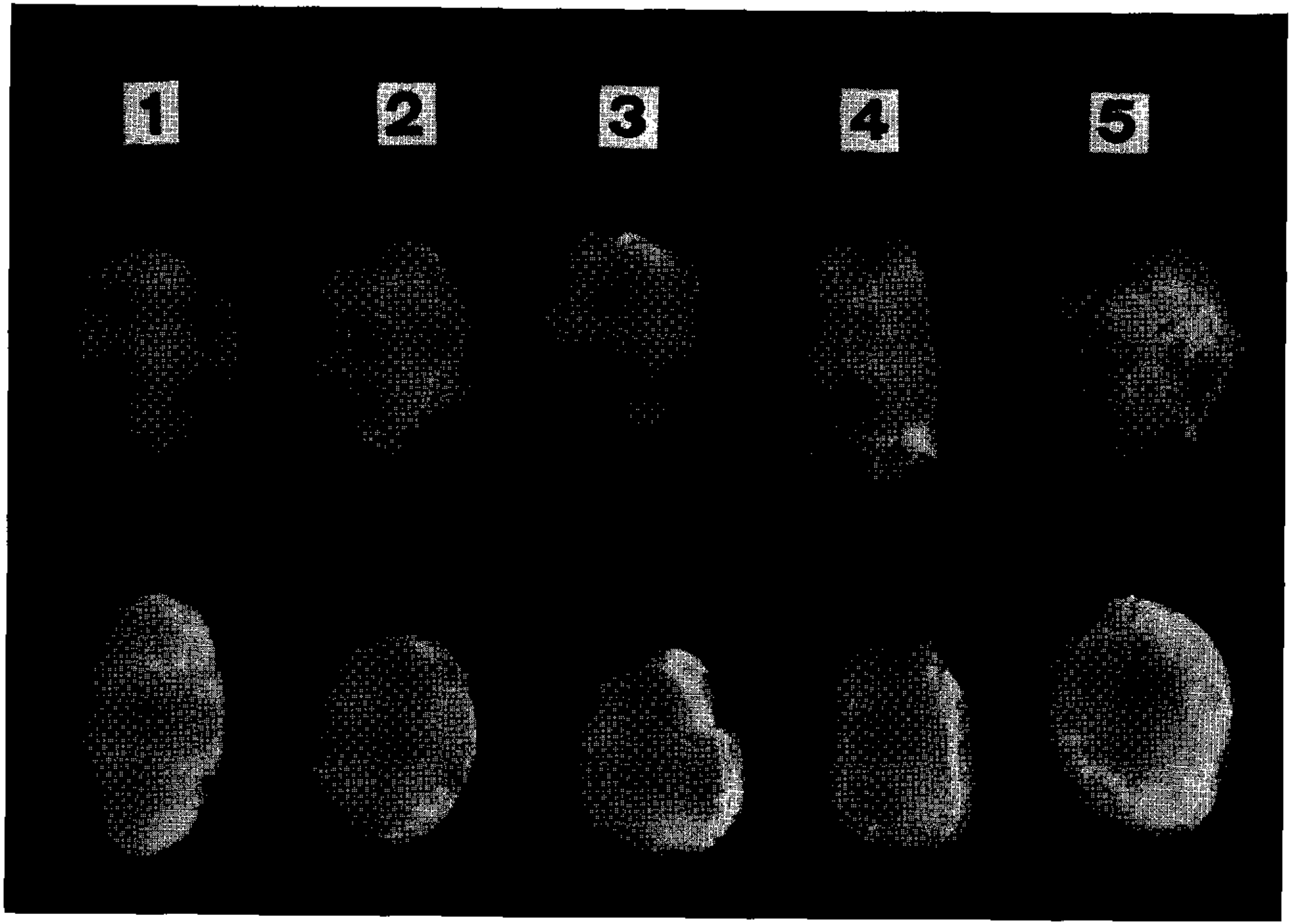

Fig. 23. Tubers (variety Libertas) of one lot separated by brine solutions in specific gravities of (from left to right) 1.080, 1.090, 1.100, 1.110 and 1.120 (The halves of both rows do not belong to each other).

(Photograph by Mr. G. Bierling, Office of Joint Services, Wageningen).

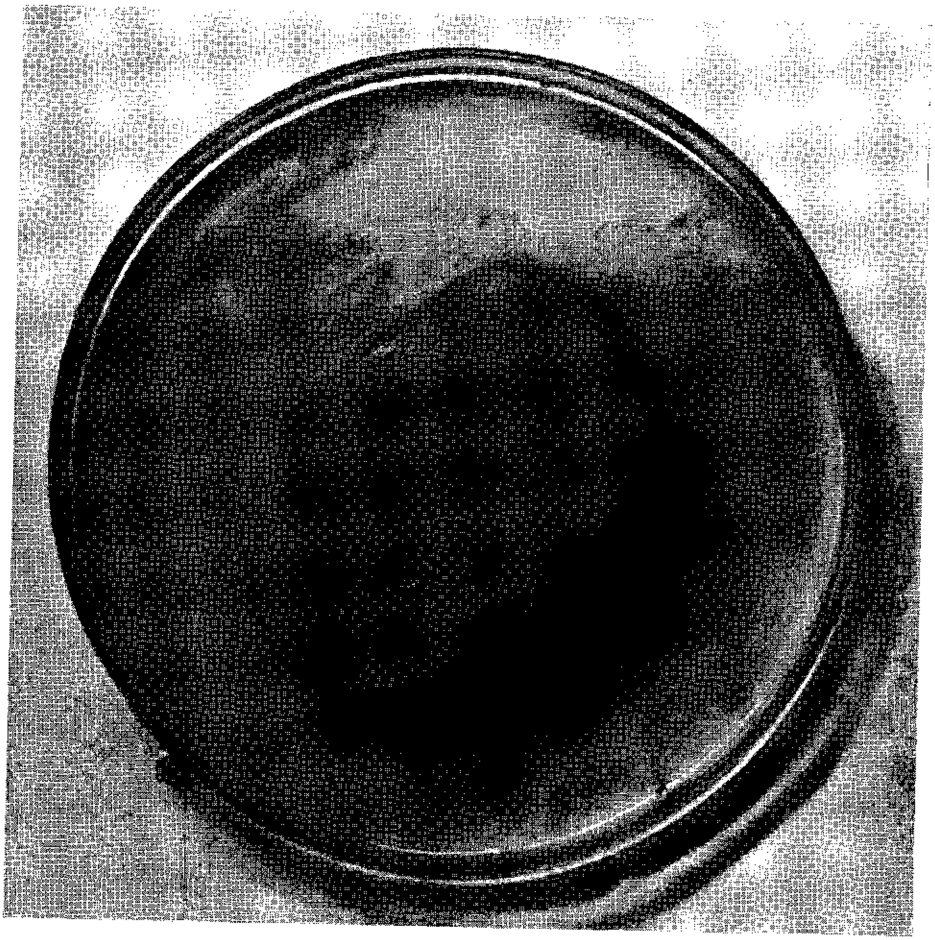

Fig. 24. Xylem bundles in a cooked tuber of the variety Libertas.

(Photograph by Mr. G. Bierling, Office of Joint Services, Wageningen).

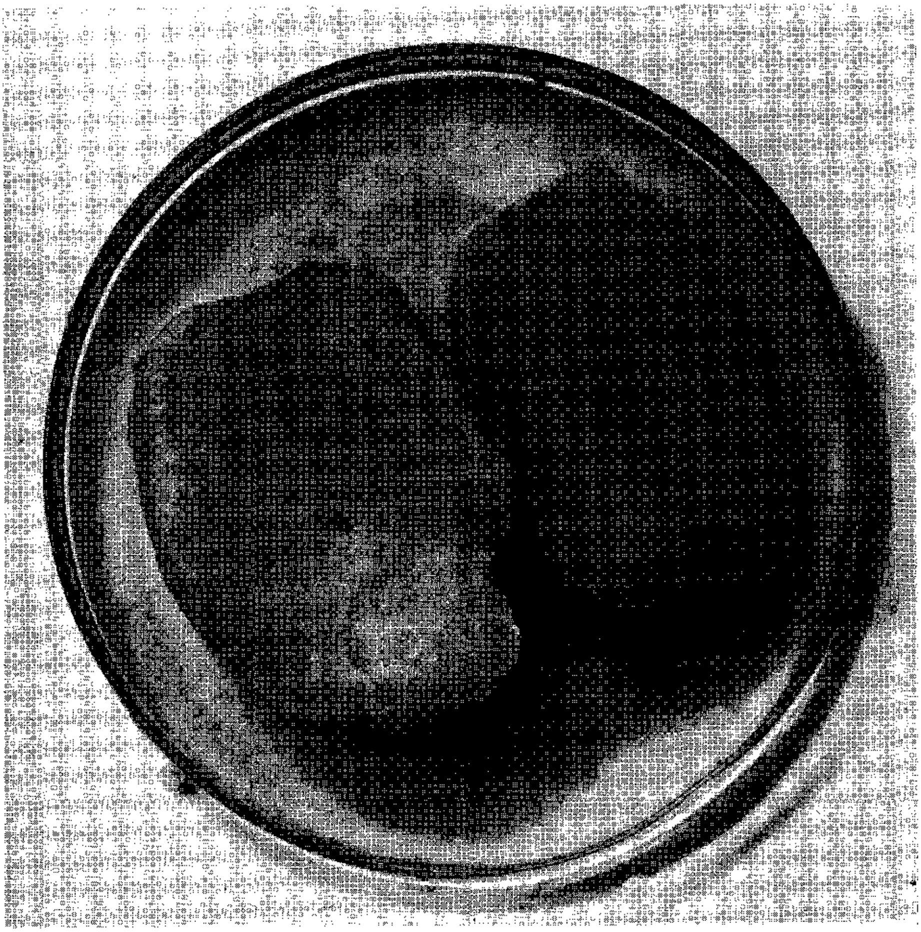

Fig. 25. Course of the xylem bundles in cooked tubers of the variety Irene (left) and Libertas (right).

(Photograph by Mr. G. Bierling, Office of Joint Services, Wageningen).

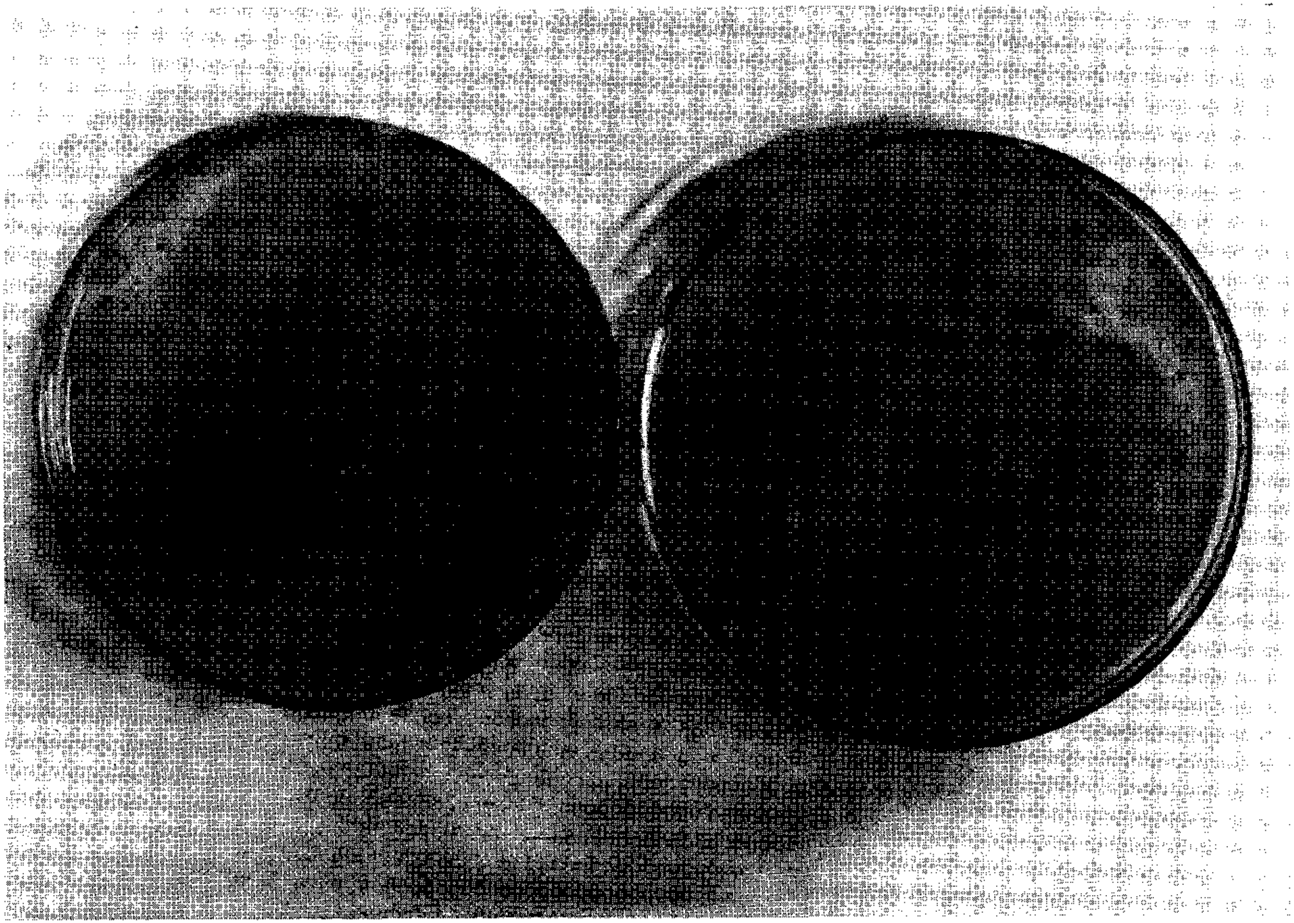

Fig. 26. Xylem bundles in cooked tissue of the varieties Irene (left) and Libertas (right). (The same samples as in fig. 25).

(Photograph bij Mr. G. Bierling, Office of Joint Services, Wageningen).

Nevertheless, an investigation in which the gradient of specific gravity was estimated by "peeling" samples of twenty potatoes repeatedly and "weighing" them under water after each removal of a "peel" (of about 2–3 mm thickness), showed that many exceptions exist. That is to say several varieties sloughed on a level of specific gravity on which most varieties did not, whereas on a higher level some varieties did not show sloughing in contrast to many other varieties. Also the gradient in specific gravity offered few points of connection.

However during judgment of many samples an observation of some importance was made. Often potatoes were judged with a specific gravity which made us expect a severe sloughing, which expectation was not fulfilled. When cutting through such cooked potatoes lengthwise a picture was obtained as of the right tuber of the lower row in figure 23 namely a very high starch content in the vascular region without any, or little, sloughing. Evidently sloughing was prevented by a certain toughness of the outer layer. To test if this toughness was caused by a high content of coagulated albumen, total nitrogen of the outer layer of two millimeters (after peeling normally) of raw tubers was determined with 12 samples, next to an estimation of total nitrogen in the rest of the tuber[1]).

The correlation coefficient between sloughing and the N-content in the dry matter of the outer layer proved to be −0.928, between sloughing and the N-content in the fresh weight of the outer layer −0.848. As the correlation coefficients between sloughing and the same characteristics in the rest of the tuber were −0.800, resp. −0.815, the conclusion seems justified that a high content of coagulated albumen in the dry matter of the outer layer of cooked potatoes causes toughness of the outer layer and therefore is the cause of an absence of sloughing in cases where sloughing could be expected from the specific gravity of the tuber. However, this hypothesis must still be proved. This fact gives us an explanation of the peculiar swarm of dots which is obtained when a dot chart is prepared with specific gravity on the abscissa and sloughing on the ordinate. Such swarms do not show a more or less elliptical form but that of a right-angled triangle with the hypotenuse on the place of the axis of the expected swarm. To the left of the left angle of the triangle no sloughing occurs, and consequently the base of the triangle is lengthened beyond the left angle of the triangle.

For the sake of completeness it should be mentioned that the correlation coefficient between sloughing and percentage dry matter of the outer layer was 0.323.

[1] These determinations were performed by the Institute for Biological and Chemical Research on Field Crops and Herbage, Wageningen, for which we thank DR. W. B. DEYS and MISS H. A. SONNEVELD.

The regression equations, which need further confirmation, were
sloughing = $-0.8212 \times$ % N in dry matter of outer layer + 7.65
sloughing = $-3.0767 \times$ % N in fresh weight of outer layer + 7.80.

This means that maximum sloughing occurs if percentage N in dry matter in the outer layer is about 4.5 or percentage N in fresh weight of the outer layer is about 1.25, provided that starch content is sufficiently high.

6.4. Results with the method for estimating fibrousness

As we mentioned before, an excessive fibrousness is not favoured by many consumers. But as only some varieties may show this, this characteristic is of minor importance. As, besides, this property is not judged but only an excessive fibrousness is noted when necessary, little need be said about the method.

Figure 24 shows a network of "fibres" and in figure 25 the course of the xylem in two tubers of different varieties can be seen. Evidently the xylem in the tuber on the right side has been developed more strongly than that on the left side. This can also be seen in figure 26 where both Petri dishes contain tissue of the same varieties as in figure 25. In the right-hand Petri dish the strong "faggot" form is visible. These varieties are characterized by a rather strong and a very strong fibrousness respectively. In such cases length of "fibres" is 1–2 cm. On the other hand several varieties, when treated as the tissue in the dishes show "fibres" of not more than 0–5 cm, which, besides, are so thin as to be hardly visible. In those cases sheaf formation is never seen.

Fibrousness was not related to specific gravity although an excessive fibrousness only occurs in varieties with a high specific gravity. Also no relation could be established between fibrousness and texture properties.

Thickness, length, and degree of sheaf formation were highly correlated in the Dutch variety trial 1960, as correlation coefficients between thickness and length, between thickness and degree of sheaf formation and between length and degree of sheaf formation were 0.904, 0.925 and 0.856 respectively. The correlation coefficients in the International variety trial 1960 were lower, namely in the same order 0.692, 0.768 and 0.893, which is caused by the fact that variation in "fibre" dimensions was much smaller than in the Dutch variety trial of the same year.

PART III

COLOUR AND DISCOLORATION

7. SOME REMARKS ABOUT COLOUR AND COLOUR MEASUREMENT

In colour three psychological components can be discerned, namely hue, saturation and lightness. These components have been described by JUDD (1952) as follows: "Hue (of a color perception) is the attribute denoted by blue, green, yellow, red, purple and so on". "Saturation (of a color perception) is the attribute determining the degree of its difference from the achromatic color perception (= one not possessing a hue) most resembling it; opposite of greyness". "Lightness (of the color perception of a nonself-luminous object) is the attribute permitting the perception to be classed as equivalent to some member of the series of achromatic object-color perceptions ranging for light diffusing objects from black to white". So differences in saturation are indicated by the opposites greyer or less grey and differences in lightness by the opposites lighter or darker.

According to the same author we meet in our every day life differences in colour which are in reality combined differences in lightness and saturation, described in one word. For instance paler is an expression for a less saturated colour with a greater lightness. This in contrast to deeper. More brilliant means lighter and more saturated as opposed to duskier.

In this nomenclature white is a neutral colour (saturation = 0) with a lightness of 1, while black is a neutral colour, but with a lightness of 0. Between them the range shows the various degrees of greyness.

NICKERSON (1946) gives an elucidating diagram, valid for given hue.

INCREASING LIGHTNESS ↑

Very pale (very light, weak)	Very light	Very brilliant (very light, strong)	Vivid (very strong)
Pale (light, weak)	Light	Brilliant (light, strong)	
Weak	Moderate (medium lightness, medium saturation)	Strong	
Dusky (dark, weak)	Dark	Deep (dark, strong)	
Very dusky (very dark, weak)	Very dark	Very deep (very dark, strong)	

INCREASING SATURATION →

The characteristics mentioned are for a certain object constant only if the nature of the light source by which the object is illuminated does not change. If the object is illuminated by another light source (for instance by incandescent light instead of natural daylight), in general all three characteristics will change in quantity and the eye will observe another colour.

The sensitivity of the observer's eye to lightness also plays a part. This sensitivity is strongly influenced by the spectral distribution of the light. JUDD (1952) states that this function – namely the sensitivity of an average normal observer to radiant energy of various wavelengths as far as the judgment of lighter or darker is concerned – is without doubt the most important psychophysical information required for fundamental colour measurement.

It appears that the eye is most sensitive to wavelengths of about 555 mμ (yellowish green). As the wavelength of the color decreases or increases, the sensitivity strongly decreases accordingly.

For a colour measurement of an object three facts must be accounted for, namely

a. The spectral distribution of the light emitted by the light source and the energy values of the components,

b. The spectral change which the light of the light source undergoes under the influence of the object before it meets the eye of the observer,

c. The sensitivity of the human eye.

On these requirements the XYZ-system is based, which was devised by the International Commission on Illumination in 1931 and which meant a revolution in colour measurement, for it then became possible to record each existing colour in an unambiguous way.

Although for an extensive discussion of these complicated matters we may refer to handbooks (e.g. BOUMA, 1946, and JUDD, 1952) and papers (e.g. SELLING, 1946, NICKERSON, 1946, FRIELE and SELLING, 1947, and FRIELE, 1954, 1956) something can be said here.

It is known that many, though not all, colours may be obtained by mixing three well-chosen primary colours in different quantities. (Primary colours are the colours by whose additive combination nearly all other colours may be produced). In the XYZ-system this idea is also present and as three colours are needed, it is clear that the system will be threedimensional. One drawback, however, would be that some colours would be characterized by negative amounts of one of the primaries because not all colours can be obtained by mixing three primary colours. As this would be very inconvenient, in the XYZ-system unreal colours were chosen as coordinate axes. A peculiarity of the system is that the Y-value always gives the luminance which is the physical equivalent of the psychological term lightness.

As it is somewhat unpractical to work with coordinates in a tridimensional space these coordinates, called the tristimulus values X, Y and Z, are reduced to the ratio of each tristimulus value to their sum, which ratios are called the chromaticity coordinates x, y and z. In the latter case only two coordinates are needed because the sum of the three coordinates equals unity, but luminance must be mentioned separately.

For a clearer presentation the chromaticity coordinates are often reduced to physical terms called dominant wavelength and purity which have approximately the meaning of the psychological terms hue and saturation respectively. JUDD (1952) states it approximately as follows: Dominant wavelength is the wavelength of the part of the spectrum required for mixing with the light by which the object is illuminated (in our case daylight) to produce the colour of the object, and purity is the amount of the spectrum component in this mixture to the sum of the spectrum and daylight components. Luminance is also given separately in this case.

Figure 27 gives a graphic presentation op the chromaticity coordinates x and y of a number of colours. The names are those proposed by KELLY (1940). All existing colours, irrespective of their lightness, can be found in the triangle bordered by the line connecting the spectral colours.

About the fundaments of the measurement the following may be said.

The first fundament is the light source. The International Commission on Illumination has defined three standard light sources, which approximate incandescent light, noon sunlight and average daylight from a completely overcast sky. As colour judgments in general are performed in natural daylight, the calculations are based on this light source, called standard light source C. As the spectral energy distribution of this light source is known, we need to know how this distribution is influenced by the illuminated object and how the human eye reacts.

The change in energy distribution under the influence of the illuminated object is estimated by exposing this object to rays of different wavelengths and measuring the percentage reflected in relation to a purely white surface. As is known, a purely white surface is defined by the fact that it will reflect all rays for 100 percent. Combining the spectral energy distribution of the light source with the reflexion data of the object will give the energy distribution which will meet the eye of the observer.

Finally we must know the reaction of the human eye to these rays. As has been mentioned before the sensitivity of the human eye depends on the

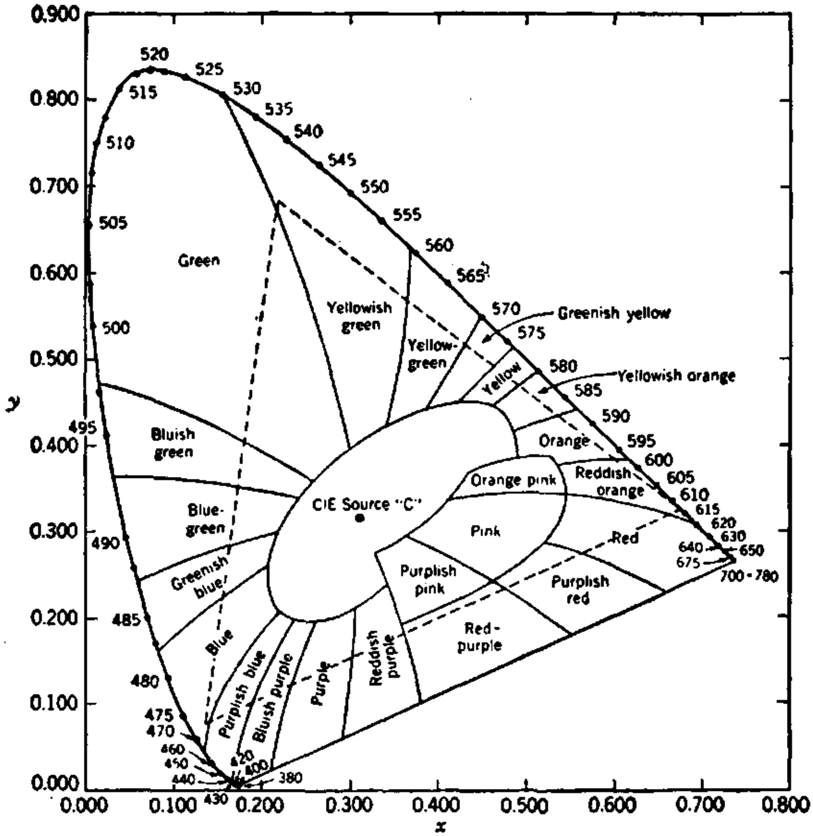

Fig. 27. Chromaticity diagram with hue names as proposed by Kelly (1940). Reprinted with permission from D. B. Judd, Color in science, business and industry, 1959, John Wiley and Sons, New York.

wavelength of the light. As, besides, personal differences in sensitivity occur, the International Commission on Illumination has defined a "standard observer". This definition has been founded on measurements GUILD (1931) and WRIGHT (1928–29) performed with a number of persons. As to the reaction of the human eye to the spectral energy distribution which meets the eye, for a better understanding it may according to FRIELE (1954) be assumed that the human eye possesses three types of elements, each of which has a specific sensitivity to the spectral colours. The sensitivities of these elements, which have been measured and may be represented by smooth curves, serve as weighting functions for the energy of the different wavelengths which meet the eye. One of these curves represents the sensitivity of the eye for lightness and is used for determining the Y-value, the remaining two for the determination of the X- and Z-values. It will be more or less clear that the determination of the tristimulus values is performed by summing over all wavelengths the following products: energy (emitted by source C) × percentage (reflected by object) × sensitivity (of the three elements separately), or

$$X = \Sigma\, E_\lambda \,.\, R_\lambda \,.\, \bar{x}_\lambda$$
$$Y = \Sigma\, E_\lambda \,.\, R_\lambda \,.\, \bar{y}_\lambda$$
$$Z = \Sigma\, E_\lambda \,.\, R_\lambda \,.\, \bar{z}_\lambda$$

in which E_λ is the energy value of a certain wavelength of the light of source C, R_λ the percentage of reflected light as compared with pure white (for this MgO is chosen) and $\bar{x}_\lambda$, $\bar{y}_\lambda$ and $\bar{z}_\lambda$ the sensitivity of the three light sensitive elements of the eye respectively.

After this very concise explanation some points of practical importance may be discussed. As the calculation of X, Y and Z would mean the performance of a great number of multiplications followed by a summation, this has been anticipated by the so called selected wavelengths. The essence of this is that these wavelengths have been chosen in such a way that the area below the curves $E_\lambda \,.\, \bar{x}_\lambda$, $E_\lambda \,.\, \bar{y}_\lambda$ and $E_\lambda \,.\, \bar{z}_\lambda$ is divided into parts with equal areas. Consequently the percentages of reflexion may be summed and the sums have to be multiplicated by certain factors.

The technique of the measurement and the calculation of the tristimulus values and other characteristics is as follows.

The object is placed next to the standard in a spectrophotometer. As standard has been chosen $MgCO_3$ instead of MgO because a perfect layer of MgO is very difficult to realise and to maintain. As $MgCO_3$ reflects about 98 % of MgO our figures are somewhat too high. The Beckman photometer type B provided with a reflexion set was used, in which light of different wavelengths obtained by a prism falls perpendicularly onto the object and the reflection is measured from an angele of 45°. The measurement of the reflexion is the radiant flux generated by the rays in a photosensitive element. By adjusting the needle to 100 when the control is measured, the percentage of reflexion is read at the moment the object is measured.

In this way the percentage of reflexion by the object is measured at wavelengths from 400 to 650 mμ, intervals being determined by the nature of the curve obtained. The smoother the form of the curve, the greater the intervals may be.

The percentages reflexion are brought onto a graph, with wavelength on the abscissa and percentage reflexion on the ordinate, and connected by a smooth line. Then the percentages of reflexion at the selected wavelengths

(10 or 30, dependent on the form of the curve) are noted, one series for the X-, one for the Y- and one for the Z-coordinate. These percentages are summed, divided by the number of selected wavelengths times 100 and multiplicated by 0.9804, 1.0000 and 1.1018 respectively, which gives the tristimulus values X, Y and Z. These multiplication factors are the tristimulus values of standard source C. Consequently if all percentages reflexion would be 100 (a purely white object), the colour emitted by source C would be seen. As has been mentioned before the Y-value is the luminance.

Table 11

Selected wavelengths for standard light source C

no	X	Y	Z
1	424.4	465.9	414.1
2ˣ	435.5	489.4	422.2
3	443.9	500.4	426.3
4	452.1	508.7	429.4
5ˣ	461.2	515.1	432.0
6	474.0	520.6	434.3
7	531.2	525.4	436.5
8ˣ	544.3	529.8	438.6
9	552.4	533.9	440.6
10	558.7	537.7	442.5
11ˣ	564.1	541.4	444.4
12	568.9	544.9	446.3
13	573.2	548.4	448.2
14ˣ	577.3	551.8	450.1
15	581.3	555.1	452.1
16	585.0	558.5	454.0
17ˣ	588.7	561.9	455.9
18	592.4	565.3	457.9
19	596.0	568.9	459.9
20ˣ	599.6	572.5	462.0
21	603.3	576.4	464.1
22	607.0	580.5	466.3
23ˣ	610.9	584.8	468.7
24	615.0	589.6	471.4
25	619.4	594.8	474.3
26ˣ	624.2	600.8	477.7
27	629.8	607.7	481.8
28	636.6	616.1	487.2
29ˣ	645.9	627.3	495.2
30	663.0	647.4	511.2

If 10 selected wavelengths are used instead of 30 the numbers marked with an asterisk have to be used.

The chromaticity coordinates are obtained by dividing each tristimulus value by the sum of the three values.

For an estimate of the dominant wavelength the simplest method is to prepare a graph like figure 27 and to draw a line through the point of source C ($x = 0.310$, $y = 0.316$, $z = 0.374$) and the point of the object, till the line which connects the spectral colours. The purity is calculated by dividing the distance between the point of source C to the point of the object by the distance of point C to the line connecting the spectral colours. The same results is obtained when the relation

$$\frac{x - x_c}{x_\lambda - x_c}, \quad \frac{y - y_c}{y_\lambda - y_c} \text{ or } \frac{z - z_c}{z_\lambda - z_c}$$

is calculated, in which x_λ, y_λ and z_λ represent the chromaticity coordinates of the dominant wavelength, x_c, y_c and z_c the chromaticity coordinates of source C and x, y and z the chromaticity coordinates of the object.

It may be remarked that the reading of the percentages of reflexion at the selected wavelengths from the graph (see table 11) is best done by using transparent paper on which next to the ordinate and abscissa the selected wavelengths for resp. X, Y and Z are indicated by vertical lines. The intersection of these lines with the curve are then read.

8. METHODS FOR THE MEASUREMENT OF COLOUR AND DISCOLORATION OF POTATOES

As will be obvious from the preceding chapter, measurement of colour requires much labour, which is not attractive when considerable numbers of samples are to be measured. Therefore an attempt has been made to simplify the procedure. A number of samples has been treated in a certain way, which will be explained in paragraph 8.3., and after this these samples have been measured. In the following paragraph the results of the measurements will be given and in paragraph 8.2. it will be shown how the measuring procedure can be simplified without losing too much in information.

8.1. The characteristics $x, y, z, \lambda_d, \epsilon, p$

The colour of the cooked samples varied from white to a very deep yellow and it may therefore be assumed that colours outside this range will not often be met with.

As is shown in figure 28 the curves obtained by bringing the percentages

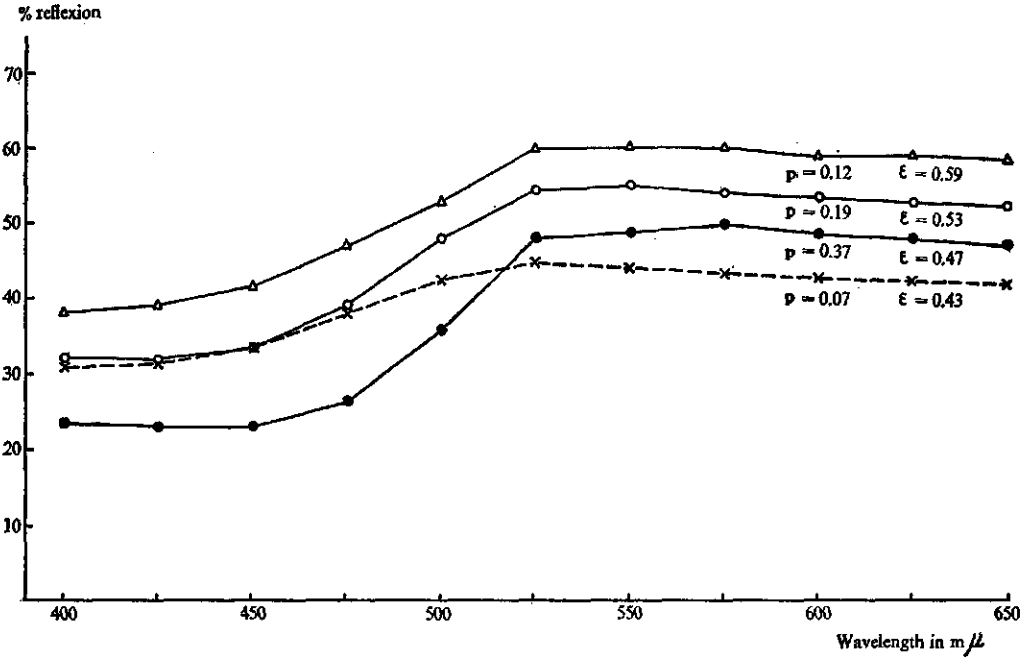

Fig. 28. Spectral reflexion curves of some samples of cooked potatoes.

reflexion onto a graph are rather smooth and therefore measurement of the potato has been performed with intervals of 25 mμ beginning at 400 mμ and ending at 650 mμ. Moreover in the calculation 10 instead of 30 selected wavelengths have been used.

Concerning the above-mentioned characteristics the following is of importance. The dominant wavelength varied in the nomenclature of KELLY (1940) from yellowgreen (on the greenish yellow side, $\lambda_d = 566$) to greenish yellow (on the yellow side, $\lambda_d = 575$). This characteristic is very uninteresting because of its small variation and therefore will be omitted in future.

As can be supposed from this small variation in λ_d, bringing the results in a figure similar to figure 27 will result in a narrow group of dots. This is indeed the case, as is shown in figure 29 and in figure 30 which is an enlargement of the former. The reason that the y- and z-coordinates are chosen is that the x-coordinate shows the least variation. As can be seen, values in y-coordinates range from about 0.345 to about 0.395 and in z-coordinates from 0.245 to 0.330. Only if an extreme sample is taken, for instance the outer layer of a very yellow tuber, this range proves to be too small. In the latter case the chromaticity coordinates concerned were $y = 0.427$ and $z = 0.175$.

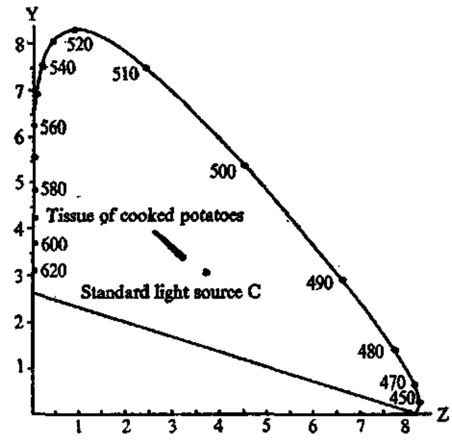

Fig. 29. Position of the colours of cooked potatoes in the (y, z)-chromaticity diagram.

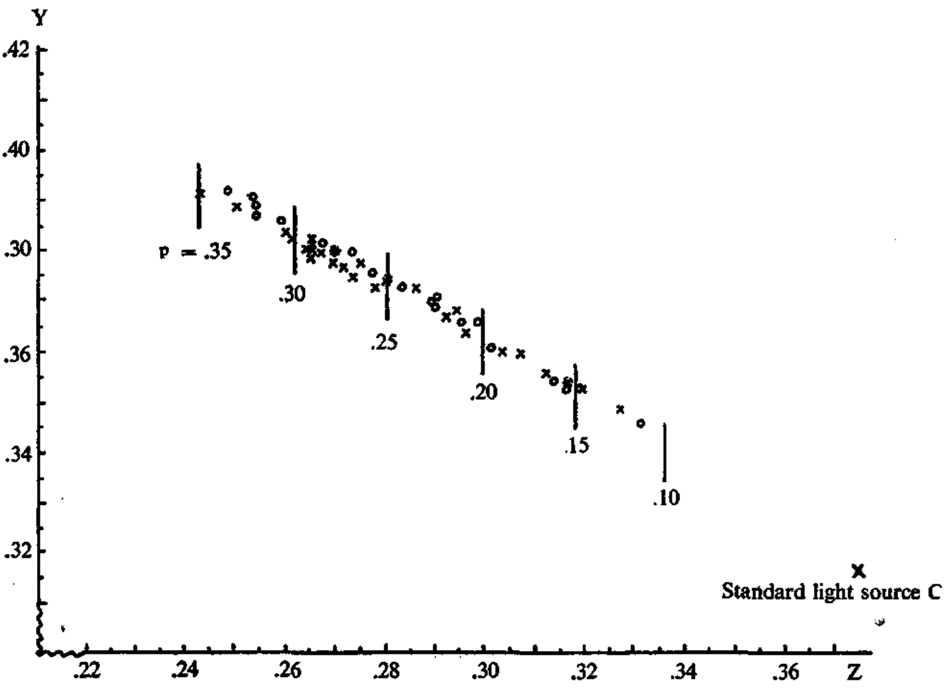

Fig. 30. Position of the colours of cooked potatoes in the (y, z)-chromaticity diagram. (p = purity).

In figure 30 the purity (p) is also shown. It is clear that differences in this respect are considerable. In the last mentioned case a purity of 0.53 was obtained.

As for the luminance (ε), this characteristic may vary from 0.30 to 0.60.

8.2. A simplified method

As reflexion curves show a striking resemblance, this offered a possibility for finding a simplified method. A study of the curves shows in the first place that luminance of the samples is greater when the level of the curves is higher and purity is greater when the slope of the curves between 450 and 525 mμ is steeper.

Studying the figures of the reflexion at the selected wavelength on one side and the luminance on the other reveals that nearly always the percentage reflexion at 525 mμ divided by 100 is 0.01 to 0.02 higher than the lightness. Indeed, the correlation coefficient between these figures was very high namely 0.994, while the regression equation was $\varepsilon = 0.0102 \times \%$ reflexion at 525 mμ $- 0.0207$.

Consequently luminance is approximated very closely if 0.02 is subtracted from 0.01 $\times$ percentage reflexion at 525 mμ.

As a measure of purity the ratio $\frac{\%\text{ reflexion at 525 m}\mu}{\%\text{ reflexion at 450 m}\mu}$ was chosen. This characteristic gave a correlation coefficient of 0.988 with purity, regression equation being

$$p = 0.2807 \times \frac{\%\text{ reflexion at 525 m}\mu}{\%\text{ reflexion at 450 m}\mu} - 0.2402.$$

It should be remarked that contrary to our expectation the difference in reflexion between 525 and 450 mμ gave a lower correlation with purity than the ratio between them, namely 0.910.

In view of these correlation coefficients in the following chapters the results with this simplified method will be mostly given. Perhaps it is not superfluous to remark that this method is not applicable to products of another colour.

8.3. The final methods

At this point some remarks should be made about the method proposed by the international working group "Potato Quality Research". This method is based on a paper by HANSEN (1935) and consists of the following. Twenty potato tubers are steamed and longitudinally cut through and peeled after reaching doneness. Discoloration of the stem end and crown end of one half of each tuber is immediately estimated according to a printed colour scale, one for white, one for yellowish-white and one for yellow potatoes as established by the Aktieselskabet Dansk Gaerings-Industri. Each contains 10 colours representing increasing discoloration from 1 to 10. The judgment is repeated after 24 hours. The totals of all judgments are added and divided by four times the number of potatoes. Multiplication with 10 gives the discoloration index.

As discoloration of the tubers can be compared with a colour chart, it might be expected that agreement between stations and the average of the working group would be rather good, but this is not the case at all. The correlation coefficients are low and considerable differences in level occur. For instance, the mean discoloration index of some stations was about two times as high as the averages of other stations. This as well as the laboriousness of the system renders this method of doubtful value.

It is a pity that this method did not give better results, for as the average of the results of the whole working group seems to have limited value, a comparison with the results of the measurement with the spectrophotometer is not very promising.

In the case of yellowness, for which the working group used a scale of 6 points (from white to deep yellow), the outlook is better. In 1961 however several stations also judged discoloration in a normal scale of four points.

Concerning the material for 1960, this was exactly the same as for texture properties (see paragraph 5.1.), namely the Dutch variety trial and the International variety trial, while for 1961 samples of the International trial and selected samples from variety trials were used.

As has been written before, for the Dutch variety trial in 1960 samples had been selected on the bases of our knowledge of the varieties, while variation was also increased by fractionating the lots into specific gravity classes. As such a selection of raw tubers is not possible for discoloration, we used the same samples for colour and discoloration measurement as for texture measurement. In 1961, however, the samples were chosen from a total of more than 300, which had been judged three times previously. Therefore variation was clearly greater than in 1960.

As the measurement has already been described in paragraphs 8.1. and 8.2. it will be sufficient to note that mostly the results obtained with the simplified method will be given. This means that correlation coefficients are calculated between the results of visual judgment and the ratio of the percentages reflexion at 525 mμ and 450 mμ (as a measure for purity) and between the results of visual judgment and the percentage reflexion at 525 mμ (as a measure of luminance).

The only important thing which must be mentioned is the method of preparation of the samples. To this end several methods have been used.

Method I: From the stem end of each of mostly 8 potatoes two slices of 3–4 cm^2 area and 3 mm thickness were cut. The members of these pairs of slices were after rinsing divided over two glass beakers of 50 ml, one of which contained water and the other – to prevent discoloration of the cooked potato tissue – a solution of 5 % sodium-metabisulfite. The slices in these beakers were cooked and after reaching doneness (after a few minutes of cooking) the liquid was poured off and the slices steamed dry. In 1960 these slices were mashed with a fork and then measured spectrophotometrically, but in 1961 the slices were pressed through a grate with holes of 2 mm diameter, then carefully kneaded after which measurement took place. In both years the colour and discoloration of the slices were judged, as well as of whole tubers of the same samples. This method served for colour and discoloration measurement both.

Method II: In 1960 tissue from the potato was pressed through a hole, as described in paragraph 5.4.1.; some samples were taken, visually judged and measured. Evidently measurement of discoloration is not possible in this way and measurement of colour concerns the whole potato and not (as in method I) the outside of the potato.

Method III. As method I but in 1961 slices were also cut from the bud end of the tubers, cooked in water, judged and measured. This served for colour and discoloration both.

Method IV: From whole cooked tubers in 1961 slices were cut of which one represented the least or not discoloring part and another the strongest discoloring part of the tuber. These slices were mashed and measured.

About the visual judgment of whole potatoes or slices it must be remarked that, as has been mentioned in chapter 7, the results are strongly dependent on the light source. Of course natural daylight is preferable but this is unfortunately not a constant light source, because it makes a difference what time of the day it is, whether the sun shines or the sky is overcast, etc. Therefore during the last years we made use of artificial light, namely two TL 33 of Philips about 1 meter above a table in a room without windows. The result is that the illumination is very constant but a disadvantage is that because of the spectrum of this light source the colours differ clearly from the colours in natural daylight. As appears from a communication of Ir. P. L.

Walraven (the Instituut voor Zintuigfysiologie R.V.O.-T.N.O. at Soesterberg, the Netherlands) a cheap and good substitute of natural daylight is obtained by using 2 TL Philips 55, combined with 1 TL Philips 15 on a height of 1 m above the table. A further improvement is obtained by painting the surroundings and the background light grey. Unfortunately we did not have the oppertunity to work with this equipment and consequently our judgments have been performed under the illumination of Philips W 33.

For the sake of completeness it may be mentioned that several daylight installations are on the market. Philips for instance, has just brought a new daylight installation.

9. RESULTS CONCERNING COLOUR MEASUREMENT

9.1. Results with the methods for measuring yellowness

1960. In the first place we were interested in the question which preparation method of the samples gave the best correlation with the visual judgment. Before going into this something may be said about the relation of the employed methods I (slices cooked in bisulfite) and II (mixed tissue). This relation is satisfactory as to purity, correlation coefficient being 0.88, but very unsatisfactory as to luminance in the Dutch variety trial, as in this case the correlation coefficient was 0.33.

The cause for this may be explained as follows. During the cooking of the slices in bisulfite it was observed that slices of several samples disintegrated rather easily. During treatment of the results it was noticed that percentage reflexion, hence luminance, was much lower as the rate of disintegration which was noted during cooking was higher. As the correlation coefficient between falling apart (resp. sloughing) of whole tubers and the difference in lightness between mixed tissue and slices cooked in bisulfite was 0.76 (resp. 0.71), it may be concluded that the method of cooking slices in bisulfite is not to be recommended if potatoes are susceptibele to falling apart or sloughing, unless special precautions are taken to prevent disintegration of slices.

To the latter fact special attention was given during cooking of the slices of the International variety trial and this resulted in an increase in correlation coefficient between luminance of tissue and luminance of slices in bisulfite to 0.71. The correlation coefficient between falling apart or sloughing and the difference in luminance between mixed tissue and slices was in this case nearly zero. Nevertheless the level of the correlation coefficient concerning purity was not attained.

It must be remarked that in no case a relation was observed between luminance and purity.

Table 12

Correlation coefficients between visual judgment of colour and (approximations of) purity and lightness in 1960.

Correlation coeff. between	Dutch variety trial	Internat. variety trial	Intern. variety trial (av. judgment of all stations)
Visual judgment of mixed tissue and			
% reflexion 525	0.833	0.926	–
% reflexion 450 / % reflexion 525 } mixed tissue	−0.084	0.251	–
Visual judgment of whole tubers and			
% reflexion 525	0.859	0.918	0.900
% reflexion 450 / % reflexion 525 } mixed tissue	−0.139	−0.220	−0.157
Visual judgment of whole tubers and			
purity } slices in bisulfite	0.805	0.808	–
luminance } slices in bisulfite	−0.407	−0.001	–

In table 12 the correlations between visual judgment and the results of measurement are given.

From this table it may be concluded that measurement of slices of the stem end of potatoes which were cooked in sodium-metabisulfite did not agree so well with the visual judgment of the colour of whole tubers as the measurement of well-mixed tissue of cooked potatoes. The second conclusion is that the correlation coefficient between the visually judged colour of whole potatoes and the ratio of the percentages reflexion at 525 mμ and 450 mμ was about as high as the correlation coefficient between the latter ratio and the visual judgment of the tissue just before measuring. The third conclusion is that the International variety trial showed higher correlation coefficients than the Dutch variety trial. This is probably due to the fact that the samples of the latter trial showed a smaller range in yellowness than those of the former. The fourth conclusion is that the relation between the average results of the whole working group and the ratio 525/450 is practically the same as the relation between our judgment of whole potatoes and the same characteristic. The fifth and last conclusion is that luminance or the approximation of luminance (percentage reflexion at 525 mμ) seems to play no part in the colour, judged visually by a scale formulated in terms as white, greyish white, creamy, light yellow, yellow and deep yellow. Still luminance or its approximation may be of some importance because in some cases the multiple correlation coefficient between visual judgment on the one hand and the approximations of purity and luminance on the other was significantly higher than the correlation coefficient between visual judgment and the approximation of purity alone, although the increase was rather small.

1961. As in this year no use was made of the cylinder in which tissue was pressed through a hole, normally cooked mixed tissue was obtained by cutting pieces of tissue from stem end and bud end of cooked potatoes. For colour measurement the pieces from the least discoloured part of the outside of whole cooked tubers were used in the Dutch variety trial. Next to this slices from the bud end of raw rubers were cooked in water and slices from the stem end of raw tubers were cooked in sodium-metabisulfite.

The correlation coefficients between judgment of whole tubers and measurement of the least discoloured pieces, slices from bud end and slices from stem end respectively were 0.863, 0.688 and 0.766. Just as in 1960 measurement of the slices resulted in lower correlation coefficients than measurement of mixed tissue from cooked whole potatoes.

In the International variety trial 1961 the correlation coefficients between our judgment of the colour of whole potatoes and measurement of the least discoloured pieces was 0.957, between colour and results of slices from bud end 0.934, between colour and figures for slices from stem end 0.857.

The correlation coefficients between average judgment of the working group and results of measurement were in the same order 0.927 and 0.894 and 0.886.

That the correlation coefficients of the International variety trial 1961 were higher than those of the Dutch variety trial must be contributed to the fact that the range in colour of the samples of the former trial was again clearly wider than that of the samples of the latter.

The regression lines, calculated with the results obtained by measuring mixed tissue of whole potatoes were:

Dutch variety trial 1960: yellowness $= 3.9471 \times \dfrac{\%\text{ refl. } 525\,\text{m}\mu}{\%\text{ refl. } 450\,\text{m}\mu} - 2.80$

Intern. var. tr. 1960 (our judgment) „ $= 4.5514 \times$ „ $- 3.42$

Intern. var. tr. 1960 (av. of working gr.): „ $= 4.3731 \times$ „ $- 3.33$

Dutch variety trial 1961: yellowness $= 3.2342 \times \frac{\%\,\text{refl. } 525\ \text{m}\mu}{\%\,\text{refl. } 450\ \text{m}\mu} - 1.73$

Intern. var. tr. 1961 (our judgment) „ $= 3.2094 \times$ „ $- 1.58$

Intern. var. tr. 1961 (av. of working gr.): „ $= 3.1318 \times$ „ $- 1.93$

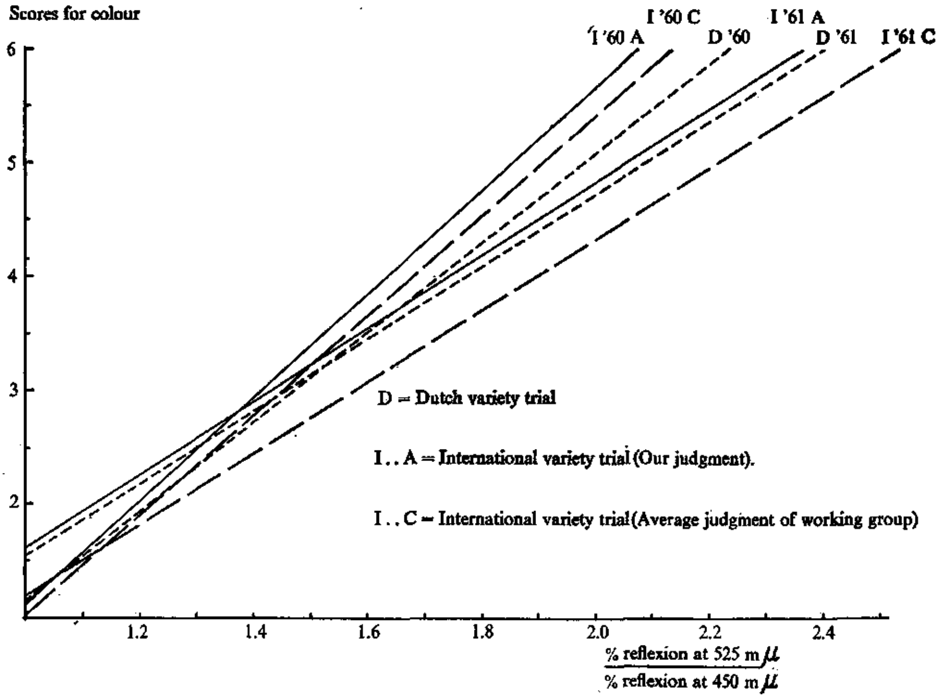

Fig. 31. Regression of scores for colour (judged in a scale of 6 points) on $\frac{\%\ \text{reflexion at } 525\ \text{m}\mu}{\%\ \text{reflexion at } 450\ \text{m}\mu}$ of mixed tissue of cooked potatoes.

In figure 31 these equations are shown. It is remarkable that the lines of 1960 are steeper than those of 1961. Undoubtedly this is caused by the difference in methods of sampling. In 1960 very thoroughly mixed tissue from the whole potato was measured, whereas in 1961 tissue from the least discoloured part of the outer layer of the potatoes was chosen for measurement. As the outside of the tubers is more yellow than the inner tissue it is clear that the ratio $\frac{\text{reflexion at } 525\ \text{m}\mu}{\text{reflexion at } 450\ \text{m}\mu}$ will be smaller if more inner tissue is present, at least in yellow potatoes. The yellower the potatoes, the greater also the influence. In white or nearly white potatoes presence of inner tissue will have little influence on slope. As in practice the colour of cooked potatoes is judged at the outside, however, the lines of 1961 represent better what is seen than the lines of 1960. Especially our judgments of the Dutch variety trial and the International variety in 1961 agree very well.

That the regression is influenced by the way of sampling may be demonstrated by the equations in table 13.

Table 13

Regression of judgment of colour of whole cooked potatoes on $\frac{\text{\% reflexion at 525 m}\mu}{\text{\% reflexion at 450 m}\mu}$ (p′) of cooked potato tissue

	Dutch variety trial 1961	Int. var. tr. '61 (our judgment)
Least discoloured part of outside of whole potatoes	3.2342 p′−1.73	3.2094 p′−1.58
Slices of bud ends cooked in water	2.5715 p′−0.15	3.1440 p′−1.08
Slices of stem ends cooked in sodium-meta-bisulfite	3.0767 p′−1.17	3.1852 p′−1.28

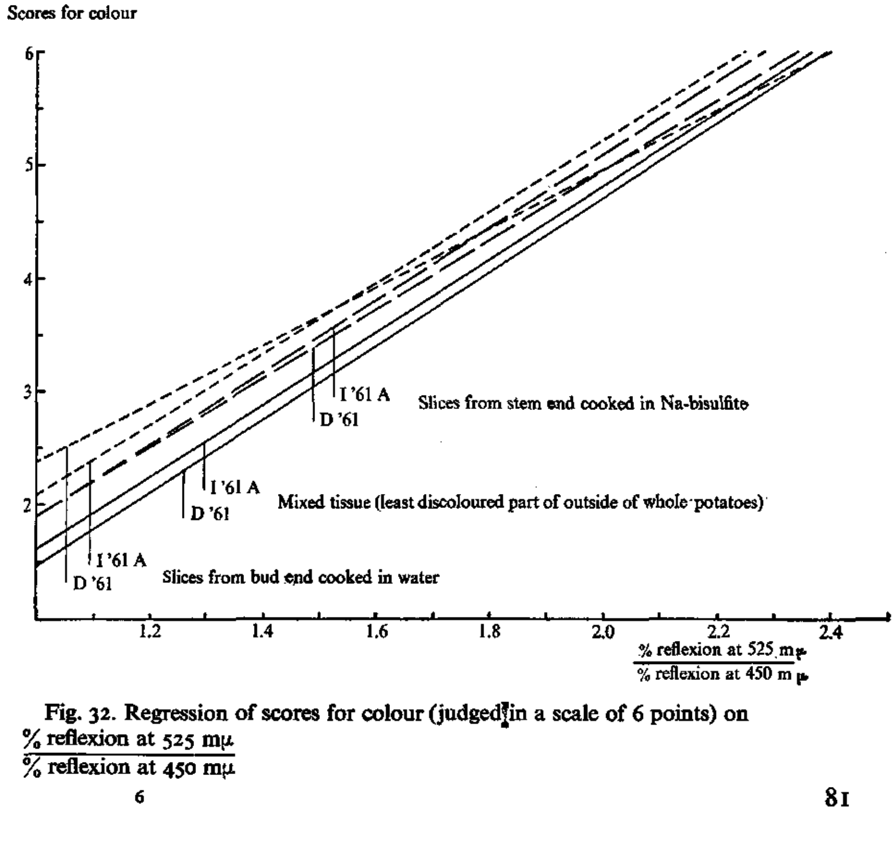

Fig. 32. Regression of scores for colour (judged in a scale of 6 points) on $\frac{\text{\% reflexion at 525 m}\mu}{\text{\% reflexion at 450 m}\mu}$

6

As appears from figure 32 the lines corresponding with the first pair of equations are situated on the lowest level, the lines corresponding with the second pair of equations are situated higher, while the line corresponding with the equations for slices of the stem end cooked in sodium-metabisulfite occupy an intermediate position. The slope in the lines of these equations differs very little with the exception of one which shows a deviating course for which no explanation can be given.

A difference is often found between the equations for the slices of the stem end cooked in bisulfite and the slices of the bud end cooked in water, as the stem end of tubers is in general more yellow than the bud end. That slices are less yellow than pieces from the outside of whole potatoes must probably be contributed to the fact that slices will be more subject to leaching of the yellow substances than the whole potato, in the first place because slices are cooked in the liquid and the potatoes are steamed above it and in the second place by the relatively large area of the slices which is in contact with the liquid. Probably this leaching will be the cause for the lower correlation coefficients with visual judgment. Apart from this, it is possible – but it has not been investigated – that during cooking of the slices the water content will change, which hardly will occur during steaming of whole potatoes. Results of KUHN a.o. (1959) point in this direction: The uptake of water during cooking of potato tissue was highly and positively correlated with specific gravity. A change in water content might result in a change in reflexion.

9.2. Results with the method for measuring discoloration

1960. The principle of measuring discoloration was to compare the results of the measurement of potato slices cooked in a solution of sodium-metabisulfite, which show no discoloration, with the results of the measurement of potato slices cooked in water, which will show after some time discoloration if the samples concerned are susceptible to this.

Unfortunately this method proved to be unsuccesful for several reasons. The first has been mentioned already, namely a varying degree of disintegration of the slices during cooking, to which the slices in bisulfite were clearly more susceptible than those in water. Figure 33 gives an illustration of this. It gives five replications of the same sample of potatoes. Concerning lines 1 it was noted that the slices in bisulfite disintegrated strongly in contrast to those in water. Likewise it was noted that the slices in water showed a strong discoloration in comparison with those in bisulfite. Nevertheless, the results of the measurement showed few differences, which besides were the

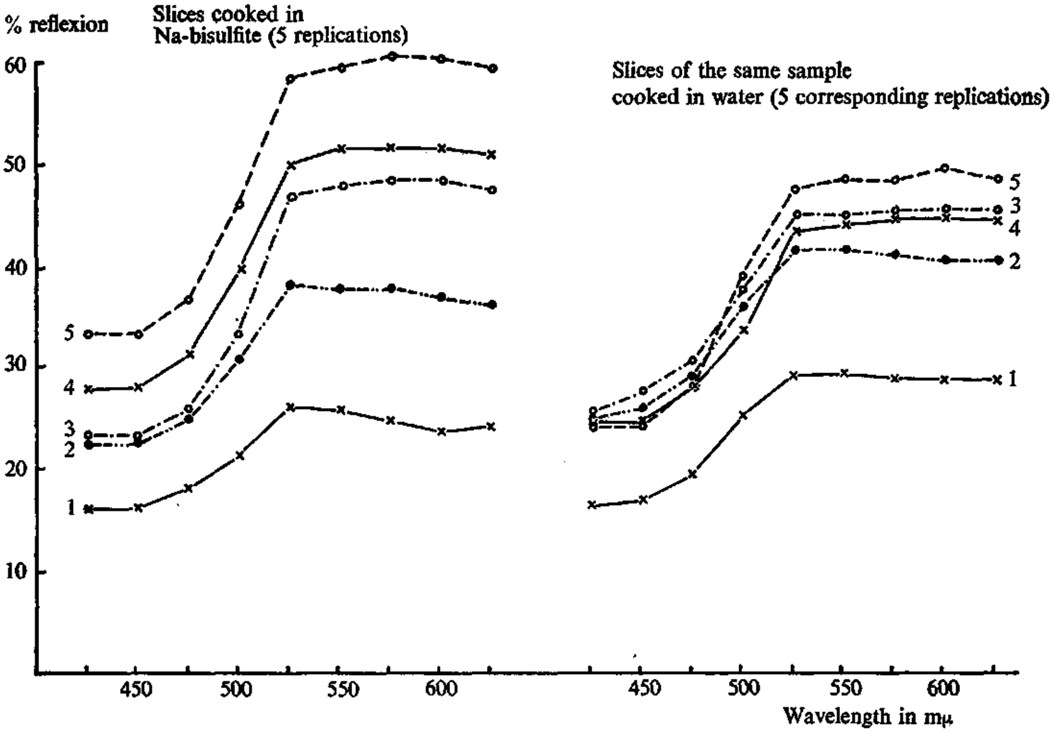

Fig. 33. Spectral reflexion curves of samples of cooked potatoes.

opposite of our expectation. The lines 5 represent samples which did not disintegrate and showed a moderate discoloration. In this case results of judgment and measurement agree well. The same is true for the lines 4 (little difference in colour), but in a lesser degree for the lines 3, and in the results of the lines 2 the same phenomenon can be seen as in the results of the lines 1.

When this became known, special care was taken to prevent disintegration during cooking of the slices of the International variety trial. This did result in a better agreement between the results of the three replications but nevertheless agreement between visual judgment and measurement results again left much to be desired.

Therefore a second cause may be active. Judging whole potatoes for discoloration means judging a difference between little or no discoloration and more discoloration, but what is measured are slices which show more or less discoloration (slices cooked in water) and slices which show no discoloration at all (slices cooked in bisulfite). If the latter does not agree with reality it is not possible to get a good agreement between judgment of whole potatoes and this method. Therefore in 1961 slices have also been cut from cooked potatoes representing the part with most and the part with least discoloration, and besides slices of the bud end of raw tubers have been cooked in water.

As a third cause we suggest that sodium-metabisulfite may have in itself an influence on the colour irrespective of its prevention of discoloration.

A fourth factor may be that tubers of the same lot may vary considerably in discoloration as is shown by the results of the samples in figure 33.

1961. This year several methods of sampling were tried, namely comparison of slices from stem end cooked in water and cooked in sodium-metabisulfite respectively (method I), comparison of slices from stem end and bud end both cooked in water (method III), and comparison of pieces of tissue representing least and most discoloured parts of the outer layer of cooked whole potatoes (method IV).

As to the approximation of the purity, the ratio $\frac{\text{reflexion at 525 m}\mu}{\text{reflexion at 450 m}\mu}$, it may be said that discoloration seems to have hardly any influence on this characteristic, and certainly not a consistent influence. The influence on the approximation of luminance, reflexion at 525 mμ, is very clear.

Nevertheless the results in the Dutch variety trial 1961 were rather disappointing, as table 14 shows. In this table the correlation coefficients between judgment of whole tubers and measurement, as well as the correlation coefficients between judgment of pieces cut from the cooked whole potatoes and measurement have been recorded. The correlation coefficient between judgment of whole tubers and judgment of least and most discoloured pieces cut from whole tubers was 0.736.

As the samples for measurement have been selected on the discoloration of the potatoes as judged earlier and consequently the judgment of pieces from whole cooked potatoes is performed with other potatoes than were used for the judgment of discoloration of whole tubers, it could be concluded that the selected samples for measurement differed rather strongly in discoloration from the tubers judged earlier. Although this may be true, it is also possible that the judgment is influenced by the way in which samples are presented. In other words, it is possible that judgment of pieces representing least and most discoloured parts of the tubers gives other results than judgment of whole tubers.

It is evident that this measurement gave a better agreement with judgment

Table 14

Correlation coefficients between judgment of discoloration and the results of measurement (Dutch variety trial 1961)

	Correlation coefficients between	
	judgm. of disc. of whole potatoes	judgm. of disc. of pieces cut from whole pot.
and difference in reflexion at 525 mμ between		
slices from stem end cooked in Na-bisulf. and water resp.	0.251	0.642
slices from bud end (water) and stem end (water)	0.265	0.340
pieces representing least and most discoloured parts of cooked whole tubers	0.399	0.501
and the ratio of the percentages reflexion at 525 mμ of		
slices from stem end in water to slices from stem end in bisulfite	−0.333	−0.694
slices from stem end (water) to slices from bud end (water)	0.112	−0.402
pieces representing most to pieces representing least discoloured parts of cooked whole tubers	−0.425	−0.486

of pieces than with judgment of whole tubers but nevertheless agreement is lower then was expected.

A fact of importance is that the ratio in reflexion between both samples gave about the same correlation coefficients as the difference in reflexion. This means that no calculation is necessary, because the standard can be replaced by the least discoloured sample of each pair. By adjusting this sample to 100 the reflexion of the most discoloured sample of the pair can be read in percentage of the least discoloured sample.

The results of the International variety trial 1961 were much more promising, probably caused partly by the greater differences in discoloration between samples. Also the fact that judgment of slices and pieces was carried out with the same tubers as were normally judged may have been contributed to this. Next to our judgment, the average figures of the working group have been used and the correlations have been calculated between measurement and the average "discoloration index", as mentioned in section 8.3. The correlation coefficient between our judgment and the discoloration index was 0.629, between the latter characteristic and the average figures of the working

Table 15

Correlation coefficients between judgments resp. discoloration index of whole tubers and results of measurement
(International variety trial 1961)

	Correlation coefficients between		
	our judgment	av. results work. gr.	disc. index
and difference in reflexion at 525 mμ between			
slices from stem end cooked in Na-bisulfite and water resp.	0.663	0.621	0.317
slices from bud end (water) and stem end (water)	0.884	0.754	0.540
pieces representing least and most discoloured part of cooked whole tubers	0.251	0.053	0.203
and the ratio of the percentage reflexion at 525 mμ of			
slices from stem end in water to slices from stem end in bisulfite	−0.630	−0.607	−0.394
slices from stem end (water) to slices from bud end (water)	−0.820	−0.705	−0.461
pieces respresenting most to pieces representing least discoloured part of cooked whole tubers	−0.202	−0.020	−0.086

group for discoloration this was 0.505. This proves that the discoloration index cannot be considered a valuable method. Table 15 gives the results of the calculations.

It is remarkable that contrary to our expectations the correlation between judgment of tubers and measurement of pieces cut from these tubers is much lower than that between judgment of tubers and measurement of slices. Evidently a comparison of bud end and stem end slices, both cooked in water, was more satisfying than a comparison between slices from stem ends cooked in water or in sodium-metabisulfite. In this trial the correlation coefficient between judgment and the difference in reflexion between the samples of each pair was somewhat higher than the correlation coefficient with the ratio. Correlation coefficients between measurement and average judgment of the working group were a bit lower than between measurement and our judgment, but nevertheless satisfactory in the case of bud end – stem end comparison whereas the correlation coefficients between measurement and discoloration index was very low. The latter fact could be expected from the correlation between judgment and discoloration index.

As most correlation coefficients are low it is not possible to get a very reliable impression of the quantitative relation between judgment and measurement. Only the results of the comparison of slices from bud ends and slices from stem ends of the International variety trial give some idea about the relation, as the difference in reflexion at 525 mμ between slices from bud end and those from stem end gives a correlation coefficient with judgment of 0.884 and the ratio of bud end to stem end slices a correlation coefficient of −0.820. The regression equations were:

Discoloration = 0.1381 (reflexion bud end slices – reflexion stem end slices) + 1.87

and

$$\text{Discoloration} = -0.0579 \left(100 \times \frac{\text{reflexion of stem end slices}}{\text{reflexion of bud end slices}} \right) + 7.71.$$

The equations based on the average judgment of the working group were:

Discoloration = 0.0828 (reflexion bud end slices – reflexion stem end slices) + 1.59

and

$$\text{Discoloration} = -0.0351 \left(100 \times \frac{\text{reflexion of stem end slices}}{\text{reflexion of bud end slices}} \right) + 5.12.$$

As usual lines based on the results of the working group are clearly less steep than those on our judgment.

PART IV

DISCUSSION AND CONCLUSIONS

10. DISCUSSION ABOUT THE RESULTS CONCERNING TEXTURE PROPERTIES

10.1. Mealiness

In chapter 4 it has been shown that the relation between mealiness and specific gravity varies quantitatively from variety to variety and from trial field to trial field. Also it has been shown that correlation coefficients between these characteristics are strongly determined by the level of the regression coefficient of mealiness on specific gravity, so that low regression coefficients often cause low correlation coefficients. This again is caused by the fact that standard deviations of specific gravity are relatively constant when comparing different trial fields. If regression coefficients are low, this means that in a normal range of 100 grams in weight under water differences in mealiness are detected with more difficulty than if regression coefficients are high. This is a normal consequence of the sensorial judgment, which is too susceptible to shifts in interpretation of the judgment scale, to the condition of judges, etc. to obtain "correct" results.

In figure 17 it can be seen that indeed the relation between mealiness and specific gravity varies quantitatively. As, however, the Dutch variety trial 1960 was judged in tenfold and the range in weight under water in this trial was very great (about 250 grams), it might have been expected that the line of this trial would have occupied a more or less average position in the figure. This is not the case at all, as the mealiness level at a given specific gravity was clearly higher than the level of any other trial. As this intermediate position can only be obtained by subtracting a full point of the scale from the mealiness figures, a shift in interpretation can hardly be used as an explanation. This points to another cause besides specific gravity.

This is supported by the fact that in several cases stickiness of the mashed tissue proved to be a valuable supplement to specific gravity or gave an even better correlation with mealiness than specific gravity. Especially the fact that the multiple regression equations calculated from the results of the Dutch variety trial 1961 and of the four "best correlating" stations of the International variety trial 1961 were practically identical seems very important, just for the reason that when comparing both trials the regression equations between mealiness and, respectively, specific gravity and stickiness showed clear differences.

At this point it is tempting to make some speculations about the nature of this second factor.

If raw tubers of two samples of potatoes which differ in mealiness are compared after cutting them in two, no differences can be observed. All that will happen is that the knife will become wet. If the same is done with cooked potatoes the knife will become at most a bit humid. Differences between both samples are easily visible: the cut surface of the mealy potato will be dry, while in the other more water will be seen as the potato is less mealy. Nevertheless water content of raw and cooked tubers of the same sample is practically the same. Evidently in less mealy potatoes the water is absorbed by the gelatinizing starch to a lesser degree than in the mealier sample. It is clear that more water will be seen as the starch content is lower. This is reflected in the relationship between specific gravity and mealiness. However, if starch content of both samples would be the same and if, in spite of that, differences in dryness in the cooked potatoes are seen, it must be assumed that in the mealier potato starch has swollen more than in the less mealy potato.

In our opinion the swelling of the starch within the cells must be considered as the second factor. As the presence of electrolytes has a strong influence on the swelling capacity of starch, it is clear that measurements in this respect have to be carried out in the juice of the potato. An observation of DOW (see SWEETMAN, 1936) is important in this respect. She found not only that 0.5 g starch in destilled water swelled during heating to a volume of 50–140 ml, whereas in potato juice only a volume of 22–33 ml was reached, but also that the same starch swelled much more in the juice of a mealy variety than in the juice of a non-mealy variety. Unfortunately, she gives too little information about the specific gravity of the tubers and about the way in which the investigation was carried out, to make possible an explanation of the fact that she found no correlation between swelling capacity of the starch and mealiness. UNRAU and NYLUND (1957) found indeed high correlation coefficients between mealiness and properties of the starch but as these properties were highly correlated with dry matter content, their material offers no proof, quite apart from the fact that the number of samples they investigated, namely seven, was rather small. It must be said that most investigations in this field have the defect that the number of samples is very small.

If, next to starch content, also the properties of the starch are responsible for differences in mealiness, the phenomenon will be observed that correlation between specific gravity and mealiness will be high if samples are judged which differ much in specific gravity but little in the property of the starch concerned, whereas in a comparison between samples with clear differences in this property the relative importance of specific gravity will decrease. In this case a multiple regression equation must be used. Where specific gravity varies little but the concerning starch property much, the latter will give a better idea about mealiness than specific gravity. It is possible, however, that future results will show that the stickiness measurement is a measure of the combined results of specific gravity and starch properties.

Another question is, which value the measurement of stickiness has, whether or not as a supplement to specific gravity, in comparison with sensory judgment. This may be tested by the results of the International variety trial in 1961. Considering the average judgment of the working group as the "correct" judgment the results of the method may be compared with the results of the separate stations.

Table 16 gives these results.

Table 16

Correlation coefficients between average judgment of mealiness of the international working group in 1961 and judgment of separate stations, specific gravity and stickiness respectively

judgment of station no 1	0.897
2	0.778
3	0.654
6	0.871
7	0.819
8	0.674
9	0.872
11	0.716
12	0.598
13	0.710
specific gravity	0.727
stickiness	—0.773

The results for stickiness show an agreement with the averages of the working group at least as good as the agreement of six of the ten stations with the average judgments. It should be borne in mind, however, that the correlation coefficient of stickiness witht he average of the four stations showing highest correlation coefficients with the average of the group was –0.845. In the latter case multiple correlation coefficients between average judgment of the four stations on the one hand and stickiness and specific gravity on the other was 0.894. It should also be remembered that the equation, which causes this multiple correlation coefficient, namely mealiness = 0.0069 × weight under water − 0.2630 × stickiness + 0.3960 was practically identical with the equation obtained from the Dutch variety trial in 1961, with the exception of the constant factor. The correlation coefficients between the judgments of these five stations separately with their average varied from 0.881 to 0.928.

10.2. Softness

In paragraph 6.2. little has been mentioned about the possibility of using specific gravity as an indication of softness. The reason for this is that correlation coefficients are in general too low to have any predictive value. These coefficients varied in the Dutch and International variety trials from 0.30 to 0.70. The low level of these correlation coefficients may partly be caused by the great variation in softness of individual tubers, but the occurrence of curvilinearity, as indicated in figure 19, may also be a reason for this. This curvilinearity has especially been experienced during 1961. After judging three times about 300 potato samples from variety trials the group of dots on the concerning dot chart showed a clear V-form. The greatest firmness was found at a specific gravity of about 1.085 (w.u.w. about 390). With increasing as well as with decreasing specific gravity softness increased, although the nature of this softness was different. At high levels of specific gravity soft potatoes will fall apart under a very light pressure of the side of a fork. They split more or less, whereas soft potatoes with a low specific gravity will never show any splitting, although the side of the fork is driven very easily through the tuber. When pressing whole cooked potatoes with a finger the former kind will split but the latter will whow a certain weakness, a kind of elasticity.

The finding of SHARMA a.o. (1959), namely that tubers with high specific gravity are firmer after cooking than those with a low specific gravity, seems in contradiction with our results. This, however, is only a seeming contradiction as the potatoes with what is called high specific gravity have a specific gravity of at most 1.085. This would in the Netherlands be considered as a rather low specific gravity as specific gravities ranging from 1.090 to 1.110 are very common here. The opinion of SHARMA is in accordance with our results, as their samples cover a range from 1.065 to 1.085.

That sometimes high positive correlations have been found between specific gravity and softness (for instance field 2, 8 and 14 in table 9) must perhaps be contributed to the fact that specific gravity was clearly higher than 1.085. In other cases, however, a high positive correlation coefficient was not found, although specific gravity was sufficiently high. As varieties may differ in the relation of softness with specific gravity (see figure 19), the variety pattern of the trial fields may cause differences in correlation coefficients.

Although a weakness or elasticity of tubers of low specific gravity seldom occurs to the extent as last year, it is encountered so frequently, especially in certain varieties, that, irrespective of other causes, this is already sufficient to render specific gravity unreliable as an indication for softness.

As to the reasons for differences in softness, SHARMA a.o. (1959) state that "hard cooking" samples are characterized by a far higher content of insoluble pectine and hemicelluloses than "soft cooking" samples. Although it is not clear whether their "hard cooking" samples indeed were done, their statement might be true. If so, this would mean that softness is caused by the resistance the cells would offer to forces which try to separate them. These forces might be external forces as used during judgment or measurement of softness as well as internal forces, as exerted by the swelling of the starch during cooking of the potatoes.

It must be mentioned that a relation between texture properties and pectic substances has never been shown unambiguously (BRIANT a.o., 1945, BETTELHEIM and STERLING, 1955 b, POTTER and MC COMB, 1957).

Given the same content and the same nature of pectic substances, it might be possible that differences in softness are found. This would be the case if in such samples starch content and conditions responsible for swelling of the starch are different. In that case the internal forces which will be shown in a spherical shape of the cells in cooked potatoes could be responsible for differences in softness, as demonstrated by the splitting of the potatoes under a light pressure. This pressure could be "the last drop in the full bucket". Sometimes this drop is not needed namely when the tension in the tissue during cooking increases to such an extent that potatoes fall apart without any external pressure.

This explanation cannot serve for the weakness or elasticity in samples with a low starch content. As rupture of the cells in potatoes with a high starch content seldom or never occurs, not even when treated roughly, and as in potatoes with low starch content cell rupture during mashing is frequently observed, possibly in these weak samples the side of the fork is not driven between the cells, as in potatoes with a high starch content, but through the cells. In that case weak cell walls would be responsible for weakness.

In very firm tubers, thus without weakness and without splitting, starch content and conditions determining the swelling of starch could be responsible for firmness together with the force which connects the cells.

So in this line of thought four factors might be involved, namely starch content, conditions responsible for swelling of the starch, the "cementing" forces and, in the case of weakness, the strength of the cell walls.

As to the value of the methods devised for measuring softness, the correlation coefficients of the measurement of the samples of the International variety trial with the average result of the working group will be compared with correlation coefficients of the judgment of the separate stations with the average of the group. Table 17 gives the results.

Table 17

Correlation coefficients between average judgment of softness of the international working group and judgment of separate stations or results of measurements

	1960	1961
judgment of station no 1	0.870	0.832
2	0.801	0.779
3	0.582	0.610
6	0.707	0.686
7	0.192	0.357
8	0.890	0.715
9	0.805	0.622
11	0.665	0.363
12	–	0.791
13	–	0.460
bar transversally	–	−0.476
bar lengthwise	–	−0.385
falling rod	0.589	0.488

The correlation coefficients between station judgment and average of the working group are mostly lower than in table 16. This proves the difficulty of the judgment. Unfortunately the results of measurement are clearly lower than the correlation coefficients of the great majority of the stations. This would mean that the attempt to find an instrumental method had not been successful.

We may point however to some facts of importance. In the first place the correlation coefficients between the measurements with the falling rod and the judgment of the Dutch variety trial 1960 were about 0.90. Also the results with the resistance measurements of the bar driven transversally or lengthwise through the potatoes in 1961 were satisfactory, correlation coefficients being −0.892 and −0.881 respectively. In the second place the regression equations concerning the number of millimeters penetration were practically identical for the Dutch variety trial in 1960 and our figures of the International variety trial 1961.

This points in the direction that the methods indeed mean something, but that for some reasons the real value of the methods in the International variety trials could not be shown. One of these reasons will be the relatively small number of potatoes which could be measured, as the measurement of the softness had to be carried out after the normal judgment of all quality characteristics of three cooking samples. As the samples were often rather small and not homogeneous, only a small number of potatoes was left for measurement. As dimensions of tubers varied strongly from sample to sample, while within samples tubers were also rather heterogeneous in this respect, this may have clouded the relation between judgment and measurement.

That a considerable number of potatoes is needed, preferably distributed over several samples cooked at different times, has been illustrated by the fact that the correlation coefficient between judgment and number of millimeters penetration of the falling rod increased from 0.699 after measuring and judging in threefold to 0.890 after measuring and judging in tenfold in the Dutch variety trial in 1960.

10.3. **Other texture properties**

As falling apart only plays a part in countries where very mealy potatoes are preferred, little need be said about this property. The percentage of tubers which fell apart under the falling rod or during cooking, if necessary supplemented with the percentage of tubers which show a rupture after treatment with the rod, may give an indication for the susceptibility to falling apart, which may occur during cooking in the domestic way. In figure 20 can be seen that falling apart may become important if specific gravity rises to 1.09 or higher, which will seldom occur in samples as preferred in most countries.

Probably falling apart may be considered as an extreme case of softness and therefore the cause will be the same.

The characteristic sloughing is more important because it is considered both as a favourable characteristic in some countries, if occurring in a moderate degree, and a very unfavourable property in most countries.

Although a mechanical method has not been devised, a sufficient picture of the degree of sloughing can probably be obtained if an estimate is made of the percentage of the outside of the tuber which is intact after cooking.

One important reason for differences in sloughing is starch content. The relation between sloughing and the radial gradient in dry matter content, as found by CULLEN (1960), could not be corroborated with our material. The nitrogen content of the outer layer, however, showed a high negative relation with sloughing in samples which on the basis of their specific gravity were expected to slough clearly. Probably in samples with a high nitrogen content in the outer layer sloughing is prevented by a tough layer of coagulated albumen. Nevertheless the opinion of CULLEN might have been valid if our potatoes had been peeled thicker than 2 mm as is the custom in our laboratory. In that case the whole tough layer or a part of it would have been removed. Removal of this layer by peeling some samples twice resulted in clear sloughing. As apparently the thickness of peeling is a factor in sloughing, we are not sure if nitrogen content estimation in samples with high specific gravity would be a method for predicting sloughing in practice, the more so as we do not know how great the resistance of the tough layer is against domestic treatment. As in practice differences in thickness of peeling but also in the way of cooking will evidently occur, samples of the same lot may show considerable differences in sloughing.

11. DISCUSSION ABOUT THE RESULTS CONCERNING COLOUR AND DISCOLORATION

11.1. Colour

By colour is understood the degree of yellowness of the cooked tubers. The yellowness can be measured very well by the ratio

$$\frac{\%\ \text{reflexion at 525 m}\mu}{\%\ \text{reflexion at 450 m}\mu}$$

of tissue of cooked potatoes. In table 18 the results are compared with the results of the separate stations of the International working group in 1960 and 1961.

The results of the method may be considered very satisfying. Regarding the quantitative relation between measurement and judgment, it may be remarked that this is influenced by the way in which samples for measurement are taken (see figures 31 and 32). Therefore sampling must be standardized clearly.

Table 18

Correlation coefficients between average judgment of yellowness of the international working group and judgment of separate stations or results of measurements

	1960	1961
judgment of station no 1	0.949	0.814
2	0.934	0.790
3	0.953	0.847
6	–	0.723
7	0.954	0.949
8	0.958	0.770
9	0.836	0.735
11	0.691	0.314
12	–	0.759
13	–	0.763
measurement of mixed tissue	0.900	0.927
slices from stem end in Na-bisulfite	–	0.886
slices from bud end in water	–	0.894

11.2. Discoloration

Although devising a method for measuring discoloration was very simple, working out such a method for practical use was more difficult than we thought. The results with the final methods varied, which was caused by several factors. The most important one is that discoloration is not evenly distributed over the tuber but occurs in patches, and that variation in discoloration between tubers may be considerable. Therefore sampling has to be done very carefully, but nevertheless a uniformly coloured surface of the sample prepared for measuring is difficult to obtain. That the colour of the surface must be distributed very evenly is caused by the fact that in the Beckman type B spectrophotometer a very small part of the sample is illuminated, namely at the utmost one square centimeter. Next to this, mixing of samples occasionally causes a great toughness of the tissue, probably by starch which is released by rupture of the cells. If this occurs it is difficult to prepare a smooth surface and it is still more difficult to obtain an evenly distributed colour.

Therefore an instrument should preferably be used, with which it is possible to measure the reflexion of larger areas. SMITH a.o. (1962b), for instance, recommend the use of the Model F Agtron for which 60 mm petri dish [illegible] be used, but they do not describe th[illegible]

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Therefore an instrument should preferably be used, with which it is possible to measure the reflexion of larger areas. SMITH a.o. (1962b), for instance, recommend the use of the Model F Agtron for which 60 mm petri dishes may be used, but they do not describe this instrument in detail.

As measurement only need to be carried out at 525 and 450 mμ, it seems that a much simpler instrument than the Beckmann B may be used.

About the chemical background of after-cooking discoloration much is known (CLAGETT, 1941, SMITH a.o. 1942, SMITH and KELLY, 1944, JUUL, 1949, HANNING and HUNSADER, 1957, BATE-SMITH a.o. 1958, SMITH a.o. 1962a, etc.) and therefore it suffices to state that the common opinion is that the grey colour is caused by the colourless product resulting from a reaction between ferrous ions and o-diphenol after cooking being oxidized to the coloured ferric form. As organic acids may compete with the o-diphenols a high acid content is favourable because the reaction products of iron ions with the acids are colourless.

In table 19 the results of measurement are compared with the results of the judgments of discoloration of the separate stations of the international working group.

Table 19

Correlation coefficients between average judgment of discoloration of the international working group in 1961 and judgment of separate stations or results of measurements

judgment of station no 1	0.865
2	0.890
3	0.600
6	0.358
7	0.791
8	0.691
11	0.650
12	0.499
difference in reflexion at 525 mμ between slices from stem end, cooked in Na-bisulfite and water resp.	0.621
ratio in reflexion at 525 mμ of slices from stem end cooked in water to slices from stem end cooked in Na-bisulfite	−0.607
difference in reflexion at 525 mμ between slices from bud end and stem end (both in water)	0.754
ratio in reflexion at 525 mμ of slices of stem end to slices from bud end (both in water).	−0.705

The correlation coefficient between average judgment of the working group with the difference in reflexion at 525 mμ between slices of bud ends of potatoes and slices from stem ends of potatoes is higher than the correlation coefficient between the average judgment and the judgment of five of the eight stations.

One remark must be made in addition to what has been written in paragraph 9.2. In that paragraph it was supposed that the ratio in reflexion between slices gave about the same results as the difference in reflexion between them, and it was said that the ratio must be preferred because of practical advantages. In general this will be the case indeed, but if white potatoes are present it is better to use the difference, as in these cases the ratio will be too high in relation to the sensorial results. This is in agreement with the results of BILHAM a.o. (1937). If, however, the difference is measured these deviations will not occur.

12. CONCLUSIONS

As has been written in the Introduction it could hardly be expected that a complete solution for measuring quality properties by instrumental methods could be given after some years of investigations. After reading the preceding chapters it will be clear that the field is becoming too wide to be covered by one research worker, if the subject is to be explored with sufficient speed. Therefore at this moment we consider the purpose of this thesis to be fulfilled, if the possibility of describing quality properties of cooked potatoes by instrumental methods has been shown.

As to mealiness, which probably is the same as dryness and coarseness of structure, it has become clear that measurement of specific gravity is insufficient for predictive purposes. The method developed for measuring mealiness, namely estimating the stickiness of mashed tissue, gave a better agreement with the sensorial results than specific gravity, but it is not clear whether this method can be used alone or in combination with specific gravity. Representative samples may easily be obtained by steaming a number of sections of tubers instead of a few whole tubers.

Measuring softness of the tubers caused more difficulties because tubers of the same lot vary strongly in this respect and this property is strongly influenced by way and duration of cooking. Therefore a great number of tubers distributed over samples which are cooked at different times is needed. Several methods have been tried but none proved superior to the others. Although sometimes high correlation coefficients between judgment and measurement were obtained, in other trials the methods failed more or less. On the basis of the positive results it seems probable that an instrumental method can be devised, if sufficient tubers and if considerable variation between samples can be obtained.

An additional difficulty is that the outer layer and the inner tissue of the potato seem to exert separate influences on softness. Specific gravity proved to be a poor indication of softness.

As falling apart is a property which is only important in some countries, little research has been carried out on this point, but nevertheless one of the methods for measuring softness may give an indication of the tendency of potatoes to fall apart during domestic treatment.

Fibrousness can be estimated easily, but is of minor importance and therefore research in this quarter has been limited.

For sloughing no method has been devised, but this property can be readily expressed in the percentage of the surface of the tuber which is intact.

Measurement of yellowness of the cooked tuber offered no difficulties.

The way of sampling of the mixed tissue for measuring will ultimately determine the coefficients of the regression equation as the proportion of inner tissue in the sample for measuring has a great influence on these.

Measurement of discoloration, however, was accompanied by many difficulties, all probably caused by the size of the sample which is measured. As to this, preparation of a sample with a homogeneous colour is very difficult because discoloration occurs in patches. For this reason and because of the simplicity of the measurement (at only two wavelengths) a simple instrument probably might be devised in which much larger samples can be measured. That being the case, measurement of discoloration would be rather simple, although research is still needed about the best way of sampling. If comparison of steamed slices cut from bud end and stem end of tubers will prove to be a good method a representative sample could easily be obtained.

As specific gravity has a limited value for predicting texture properties, other causes must be at work. An attempt to specify these causes has been made, but it will be clear that very little is known about the chemical and physical background of texture properties. Therefore research in this field is needed and preferably in a more systematical way than the incidental attempts with too few samples which are mentioned in literature.

As the exchange of potato samples by members of the international working group "Potato Quality Research" of the European Association for potato Research proved to be a very valuable way for comparing results of sensorial judgment, it is to be hoped that this exchange will be continued in following years, but now with the special purpose of developing and testing methods. In that case a greater uniformity in size of potatoes is needed. Next to this it would be advisable to aim at a greater variation in quality characteristics instead of the exchange of samples which are considered representative for the quality preferred in the respective countries.

SUMMARY

Chapter 1 contains, after some remarks about the motives for this work, a description of the quality properties of cooked potatoes, considered important by the international working group "Potato Quality Research" of the European Association for Potato Research, namely colour (yellowness), discoloration, sloughing (disintegration), falling apart, softness (consistency), mealiness, dryness and (coarseness of) structure.

In **chapter 2** the advantages and disadvantages of sensorial and instrumental methods are discussed. The disadvantages of sensorial judgment of the cooking quality of potatoes may be summarized as follows:

a. The number of samples to be judged daily is limited.

b. Because of the limited size of the cooking samples representativity can only be guaranteed by cooking and judging several subsamples, which limits the daily capacity still more.

c. The possibility exists that the judgment of several properties is influenced by the value of other properties.

d. In spite of considerable experience and continuous training judgment is not always constant and reliable.

e. Interpretation of a judgment scale is not always constant but may change in the course of time.

f. Different groups of judges may differ strongly in their appreciation of the description of the points of the scale.

g. The judges should be tested for their ability for this work.

As advantages may be mentioned:

a. Preparation of samples is simple.

b. Judgment takes little time.

Advantages to be expected by instrumental methods are:

a. Capacity may be increased considerably.

b. Representativity may be improved as an increase in the number of subsamples is less difficult to realize than in the case of sensory judgment.

c. Measurement of a property is not influenced by the results of the measurement of other properties.

d. The continuous training of personnel is less necessary for obtaining constancy in results.

e. When the relation between instrumental results and judgment has been established unambiguously shifts of the interpretation play no part.

f. Interested people (plant breeders, technologists, etc.) need not ask for potatoes of a certain mealiness, whatever they mean by that, but potatoes which give certain numerical results obtained by a specified method.

g. Testing of the senses of the judges is not necessary.

As disadvantages may be considered:

a. Probably preparation of samples and measuring will take more time than preparation of samples for cooking and judgment.

b. There is a danger of automatism without meaning. Therefore measurement must be accompanied regularly with sensory observation.

In **chapter 3** the relation between texture properties is investigated. It could be shown that relations between these properties are only found when variation in texture properties is sufficiently great to be detected. Consequently, the finding of low correlation coefficients is no proof of a weak relation, but is probably caused by variation in properties being too small to show the relation by sensorial judgment. Nevertheless there are some varieties some properties of which strongly deviate from what is expected by their other texture properties.

As a consequence of the above, correlation coefficients between texture properties are strongly influenced by the condition and ability of judges, while regression coefficients also vary strongly among judges because of differences in interpretation of the scale. If, however, personal influences are diminished by averaging the results of the international working group "Potato Quality Research", these results point to the probability that mealiness, dryness and structure are three names for one property. Softness clearly occupies a more or less separate position while sloughing seems to be related to softness as well as to mealiness.

In **chapter 4** an intensive exploration into the relation between specific gravity and texture properties is made. In accordance with literature on this subject the qualitative relation between texture properties and specific gravity shows strong variations. However, it does not seem probable that this variation in qualitative relation really exists, but it must be assumed that this variation is caused by differences in the quantitative relations, which were clearly shown. If, namely, the regression of texture properties on specific gravity is low, a long range in specific gravity is needed to show the qualitative relation. If this range is too short we are not able to establish beyond doubt the qualitative relation by sensory judgment. Is the regression high, then a much shorter range suffices to show the qualitative relation. As samples of most variety trial fields show a range of 100 grams in weight under water, the consequence is that the correlation coefficient between specific gravity and texture properties only lies on a high level when the regression of texture properties on specific gravity is sufficiently high.

This variation in the quantitative relation between texture properties and specific gravity is caused by growing conditions as well as by the variety pattern of the trial field. About the latter fact it is known that some varieties are judged mealier, softer, etc. than other varieties at the same level of specific gravity.

It is evident that specific gravity alone has a very limited predictive value.

Chapter 5 gives a description of the material used and the methods applied to cooking and judging the potatoes. Next to this the methods for measuring texture properties are explained. Regarding the latter it is clear from chapter 3 that not for each property which is judged a method is necessary, but that methods must be devised for mealiness, softness and sloughing.

Mealiness is measured by the stickiness of mashed tissue, while for softness the resistance of the potato against the pressure of a metal bar, driven into the tuber, is estimated. For measurement of sloughing, however, no mechanical methods seemed suited.

Next to this the property fibrousness has been estimated after colouring the xylem in tissue which is treated in a certain way.

With respect to sloughing it may be remarked that nitrogen determinations in the outer layer of raw tubers have been carried out to investigate the degree in which coagulated albumen in the outer layer of the tuber might be responsible for the absence of sloughing in samples with a high specific gravity.

In **chapter 6** the results concerning texture properties are presented. A good measure for mealiness of the potato is the stickiness of mashed tissue, evidently better than specific gravity. As sometimes the multiple correlation coefficient between mealiness on the one hand and stickiness and specific gravity on the other was significantly higher than the correlation coefficient between mealiness and stickiness, this would mean that a multiple regression equation would give a better approximation of mealiness than the regression equation of mealiness on stickiness alone. Mostly such a supplemental effect of specific gravity was not found, thus making further research on this point necessary.

With regard to softness results were varying. If, however, the influence of variation between tubers is restricted by increasing the number of potatoes, and the influence of cooking duration is restricted by distributing tubers over several samples cooked at different times, it is to be expected that ultimately a method for measuring softness can be found.

The tendency of the tubers to fall apart during domestic treatment, which is rougher than the treatment in our laboratory, may probably be measured by one of the methods for the measurement of softness. As, however, falling apart is internationally of minor importance, the work in this direction has been restricted. The same may be said about fibrousness, the estimation of which is very simple.

For sloughing, for which no mechanical method was devised, the simplest method would probably be the most accurate, viz. estimating the percentage of the surface of the tubers which is intact. Photographs could be of great help in this respect. As sloughing depends in the first place on specific gravity and severe sloughing may therefore be expected in samples with a high specific gravity, an absence of sloughing in these samples must be caused by another factor. Probably a high content of nitrogen in the outer layer of the potato plays a part. Evidently this layer becomes tough during cooking by coagulating of the albumen, thereby preventing sloughing. If, however, potatoes are peeled thicker than is customary in the laboratory or are handled in a rougher way during or after cooking the effect of this outer layer may decrease and therefore it is doubtful if nitrogen content of the outer layer would be a good measure for sloughing. Possibly the radial gradient in specific gravity will then be more important.

In **chapter 7** the principles of colour and colour measurement according to the X.Y.Z.-system of the International Commission on Illumination are dealt with, while in **chapter 8** the methods for the measurement of colour and discoloration of cooked potatoes are explained. A quick and sufficiently accurate method of measuring the samples was devised, which gave good approximations of the characteristics luminance and purity. In this way the number of samples to be tested daily could be increased considerably.

Chapter 9 gives the results of the methods for measuring colour and discoloration. As to colour (yellowness) results were very good, but the ultimate regression equations will depend on the way in which the samples are prepared. The results of the method for measuring discoloration varied somewhat, but were nevertheless promising.

In **chapter 10** the results concerning texture properties are discussed. The need for more fundamental knowledge is put forward. It is supposed that next to starch content the conditions determining the swelling of the starch in the potato during cooking are responsible for mealiness, while these characteristics also play a part in determining softness. In the latter case, however, more knowledge about the behaviour of the cell cementing material and, in certain cases, the strength of the cell walls is needed.

In **chapter 11** the results with the methods concerning colour and discoloration are discussed. The desirability of using an instrument which measures the percentage reflexion only at 450 and 525 mμ of a larger area than is possible with the instrument used (Beckman B) is pointed out. In this way difficulties arising from preparation of the sample will be diminished, which would be very important for measuring discoloration.

In **chapter 12** it is concluded that the possibility is shown for measuring several quality properties of cooked potatoes by instrumental methods, and that further research is needed not only on the methods but also on the chemical or physical background of quality properties. The hope is expressed that the international working group "Potato Quality Research" of the European Association for Potato Research will continue the exchange of samples, but now with the express purpose of developing and testing methods for quality measurement.

SAMENVATTING

In **hoofdstuk 1** wordt, na enkele opmerkingen omtrent de aanleiding tot dit onderzoek, een beschrijving gegeven van de kwaliteitseigenschappen van gekookte aardappelen die als belangrijk worden beschouwd door de internationale werkgroep "Potato Quality Research" van de European Association for Potato Research, namelijk kleur (geelheid), verkleuring, bloemigheid, stukkoken, zachtheid (consistentie), meligheid, droogheid en (grofheid van) structuur.

In **hoofdstuk 2** worden voor- en nadelen van zowel zintuigelijke als instrumentale methoden besproken.

De nadelen van zintuigelijke beoordeling van de kookkwaliteit van aardappelen kunnen als volgt worden samengevat:

a. Het aantal per dag te beoordelen monsters is beperkt tengevolge van het spoedig optreden van vermoeidheidsverschijnselen bij de beoordelaars.

b. Tengevolge van het beperkte aantal knollen per kookmonster kan de representativiteit slechts worden gegarandeerd door verscheidene submonsters te koken en te beoordelen waardoor de dagelijkse capaciteit nog verder wordt beperkt.

c. De mogelijkheid bestaat dat de beoordeling van verscheidene eigenschappen wordt beïnvloed door de waarde van andere eigenschappen.

d. Ondanks een aanzienlijke ervaring en voortdurende training kan men niet zeker zijn van een constant en betrouwbaar oordeel.

e. De interpretatie van een beoordelingsschaal is niet altijd constant maar kan in de loop van de tijd veranderen.

f. Voor verschillende groepen beoordelaars kan de persoonlijke waardering van de omschrijving van de punten van de beoordelingsschaal sterk variëren.

g. De proefpersonen behoren te worden getoetst op hun geschiktheid voor dit soort werk.

Als voordelen kunnen worden genoemd:

a. Het toebereiden van de monsters is eenvoudig.

b. Een beoordeling vraagt weinig tijd.

Voordelen die van instrumentale methoden kunnen worden verwacht zijn:

a. De capaciteit kan aanzienlijk worden opgevoerd.

b. De representativiteit kan worden verbeterd doordat het opvoeren van het aantal submonsters minder bezwaarlijk is.

c. Het meetresultaat van een eigenschap wordt niet beïnvloed door de resultaten van de meting van andere eigenschappen.

d. Een voortdurende training van personeel is minder noodzakelijk.

e. Wanneer het verband tussen de resultaten van de metingen en de resultaten van de beoordeling op de een of andere wijze zijn vastgelegd, spelen verschuivingen in appreciatie geen rol meer.

f. Geïnteresseerden (veredelaars, technologen, etc.). behoeven niet meer te vragen om aardappelen van een bepaalde meligheid, wat ze daar ook onder verstaan, maar naar aardappelen die bepaalde numerieke resultaten geven, verkregen volgens een gespecificeerde methode.

g. Testen van de zintuigen van de proefpersonen vervalt.

Als nadelen kunnen worden beschouwd:

a. Het is mogelijk dat voorbereiding en meting meer werk kosten dan het koken en beoordelen van monsters op de gebruikelijke wijze.

b. Het gevaar bestaat dat men vervalt tot automatische metingen zonder dat men duidelijk voor ogen heeft wat men doet; daarom moeten metingen regelmatig vergezeld gaan van zintuigelijke waarneming.

In **hoofdstuk 3** is het verband tussen textuureigenschappen onderzocht. Aangetoond werd dat alleen dan een verband tussen deze eigenschappen werd gevonden wanneer de variatie in eigenschappen voldoende groot is om verschillen te ontdekken. Dit wil zeggen dat lage correlatiecoëfficiënten geen bewijs zijn voor het ontbreken van een verband, maar waarschijnlijk worden veroorzaakt door de onzekerheid van de zintuigelijke beoordeling. Niettemin worden er soms rassen aangetroffen waarvan bepaalde eigenschappen duidelijk afwijken van wat men op grond van hun overige textuureigenschappen zou verwachten.

Als gevolg van het bovenvermelde worden de correlatiecoëfficiënten tussen textuureigenschappen sterk beïnvloed door de conditie en de kundigheid van de beoordelaars, maar bovendien variëren van beoordelaar tot beoordelaar de regressiecoëfficiënten sterk tengevolge van verschil in appreciatie van de schaal. Indien echter persoonlijke invloeden worden verminderd, wijzen de resultaten van de internationale werkgroep "Potato Quality Research" op de waarschijnlijkheid dat meligheid, droogheid en structuur verschillende namen zijn voor dezelfde eigenschap. Zachtheid (consistentie) is een min of meer aparte eigenschap en bloemigheid neemt een positie in tussen meligheid en zachtheid.

In **hoofdstuk 4** is de relatie tussen soortelijk gewicht en textuureigenschappen intensief onderzocht. Overeenkomstig de literatuur over dit onderwerp is het kwalitatieve verband (uitgedrukt in de correlatiecoëfficiënt) tussen soortelijk gewicht en textuureigenschappen zeer variabel. Toch moet het niet waarschijnlijk worden geacht dat dit inderdaad het geval is, maar veeleer moet worden aangenomen dat deze variatie wordt veroorzaakt door verschillen in kwantitatief opzicht (uitgedrukt in de regressiecoëfficiënt) die duidelijk zijn aangetoond. Indien namelijk de regressie van textuureigenschappen op soortelijk gewicht op een laag niveau ligt betekent dit, dat een lang soortelijk gewichtstraject nodig is om het kwalitatieve verband aan te tonen. Indien dit traject te kort is, is het niet mogelijk met behulp van zintuigelijke methoden de mate van dit verband op een betrouwbare wijze vast te stellen. Wanneer de regressie echter hoog is, is een veel korter traject voldoende om het kwalitatieve verband aan het licht te brengen. Merkwaardigerwijze vertoont het traject van de monsters van rassenproefvelden vrijwel altijd een lengte van ongeveer 100 gram in onderwatergewicht en tengevolge hiervan ligt de correlatiecoëfficiënt tussen soortelijk gewicht en textuureigenschappen op een hoog niveau indien de regressiecoëfficiënt voldoende hoog is.

De variatie in regressiecoëfficiënten van textuureigenschappen op soortelijk gewicht wordt zowel door groeiomstandigheden als door rasinvloeden veroorzaakt. Wat het laatste betreft, het is een bekend feit dat bepaalde rassen bij een bepaald soortelijk gewicht meliger of zachter zijn dan andere.

Het is duidelijk dat het soortelijk gewicht slechts een beperkte waarde heeft als methode om de kwaliteit te voorspellen.

Hoofdstuk 5 is gewijd aan een beschrijving van het gebruikte materiaal en aan de toegepaste methoden met betrekking tot koken en beoordelen van de aardappelen. Bovendien worden de ontwikkelde methoden voor het meten van textuureigenschappen uiteengezet. Uit hoofdstuk 3 blijkt dat niet voor elke textuureigenschap een methode noodzakelijk is, maar dat kan worden volstaan met methoden voor meligheid, zachtheid en bloemigheid.

De meligheid wordt vastgesteld door meting van de kleverigheid van fijngemaakt weefsel van gekookte aardappelen. De zachtheid wordt gemeten door de weerstand tegen de druk van een metalen staaf vast te stellen, die in de gekookte knol wordt gedreven. Voor de meting van de bloemigheid echter leek geen mechanische methode geschikt. De eigenschap vezeligheid werd bepaald na het kleuren van de houtvaten in weefsel dat op een bepaalde wijze werd behandeld.

Met betrekking tot bloemigheid moet worden opgemerkt dat stikstofbepalingen in de buitenste laag van rauwe aardappelen zijn uitgevoerd om na te gaan in hoeverre coaguleerbaar eiwit in de buitenste laag van de knollen verantwoordelijk zou kunnen zijn voor het niet-optreden van bloemigheid bij aardappelen met een hoog soortelijk gewicht.

In **hoofdstuk 6** worden de resultaten betreffende textuureigenschappen naar voren gebracht. De kleverigheid van het fijngemaakte weefsel bleek een goede maat voor de meligheid te zijn, duidelijk beter dan het soortelijk gewicht. Daar soms de multiple correlatiecoëfficiënt tussen enerzijds meligheid en anderzijds soortelijk gewicht en kleverigheid significant hoger lag dan de correlatiecoëfficiënt tussen meligheid en kleverigheid, zou dit beteken dat de multiple regressievergelijking een betere benadering van de meligheid zou geven dan de regressievergelijking van meligheid op kleverigheid alleen. Meestal werd een aanvullende invloed van het soortelijk gewicht niet gevonden en is verder onderzoek op dit punt dus nodig.

Met betrekking tot de zachtheid waren de resultaten wisselend. Indien echter de invloed van de variatie tussen knollen wordt beperkt door een groter aantal knollen, en de invloed van kookduur wordt beperkt door de knollen te verdelen over monsters die op verschillende tijdstippen worden gekookt, kan worden verwacht dat uiteindelijk een methode voor het meten van de zachtheid wordt gevonden.

De neiging voor stukkoken van de knollen bij huishoudelijke behandeling, die ruwer is dan de behandeling in het laboratorium, kan waarschijnlijk worden vastgesteld met een van de methoden voor het meten van de zachtheid. Daar stukkoken, internationaal gezien, van minder betekenis is, is het onderzoek in deze richting beperkt. Hetzelfde kan worden gezegd omtrent de vezeligheid die op eenvoudige wijze is vast te stellen.

Voor de bloemigheid, waarvoor geen mechanische methode werd ontworpen, is waarschijnlijk de eenvoudigste methode de beste, namelijk het schatten van het percentage van het oppervlak van de knollen dat intact is. Foto's zouden hierbij een grote steun kunnen zijn. Daar bloemigheid in de eerste plaats samenhangt met soortelijk gewicht en daarom sterke bloemigheid mag worden verwacht in monsters met een hoog soortelijk gewicht moet een afwezigheid van bloemigheid in deze monsters door een andere factor worden verklaard. Een hoog stikstofgehalte in de buitenste laag van de knol speelt hierbij waarschijnlijk een rol. Blijkbaar wordt deze laag tijdens het koken taai door coagulering van eiwit en wordt het optreden van bloemigheid belet. Indien de knollen dikker worden geschild dan in het laboratorium de gewoonte is of ruwer worden behandeld tijdens of na het koken, zal de invloed van deze laag afnemen en daarom is het niet zeker of stikstofgehalte van de buitenste laag een goede maatstaf voor de te verwachten bloemigheid zou zijn. Mogelijk is het radiale verloop van soortelijk gewicht dan belangrijker.

In **hoofdstuk** 7 worden de principes van kleur en kleurmeting volgens het X.Y.Z.-systeem van de Internationale Commissie voor Belichtingskunde behandeld, terwijl in **hoofdstuk** 8 de methoden voor het meten van kleur en verkleuring van gekookte aardappelen worden uiteengezet. Een snelle en voldoende nauwkeurige meetmethode werd uitgewerkt, die een goede benadering gaf van de eigenschappen helderheid en verzadigingsgraad. Het aantal dagelijks te meten monsters kon hierdoor aanzienlijk worden opgevoerd.

Hoofdstuk 9 geeft de resultaten van de methoden voor het meten van kleur en verkleuring. Met betrekking tot de kleur (geelheid) waren de resultaten zeer goed, maar de uiteindelijke regressievergelijking zal afhangen van manier waarop de monsters worden bereid. De resultaten van de methode voor het meten van de verkleuring waren wat wisselend, maar toch niet zonder betekenis.

In **hoofdstuk** 10 worden de resultaten ten aanzien van textuurkenmerken besproken. De behoefte aan meer fundamentele kennis wordt naar voren gebracht. Verondersteld wordt dat naast zetmeelgehalte de omstandigheden in de knol die het zwellen van het zetmeel tijdens het koken bepalen, verantwoordelijk zijn voor de meligheid, terwijl deze kenmerken eveneens een rol spelen met betrekking tot de zachtheid. In het laatste geval echter is tevens meer kennis nodig omtrent het gedrag van de stoffen die de cellen aan elkaar kitten, evenals, in bepaalde gevallen, omtrent de stevigheid van de celwanden.

Hoofdstuk 11 geeft een bespreking van de resultaten met de methoden voor meting van kleur en verkleuring. De wenselijkheid wordt aangeduid te beschikken over een instrument dat slechts het percentage reflexie bij 450 en 525 mμ meet van een groter oppervlak dan bij het gebruikte instrument (Beckman B) mogelijk is. Op deze wijze kunnen moeilijkheden, die door de bereiding van het monster worden veroorzaakt, worden verminderd, wat voor het meten van de verkleuring zeer belangrijk is.

In **hoofdstuk** 12 wordt geconcludeerd dat de mogelijkheid voor het meten van verscheidene kwaliteitseigenschappen van gekookte aardappelen met behulp van instrumenten is aangetoond en dat verder onderzoek noodzakelijk is, niet alleen omtrent de methoden maar evenzeer met betrekking tot de chemische of physische achtergrond van de kwaliteitseigenschappen. De hoop is uitgesproken dat de internationale werkgroep "Potato Quality Research" zal voortgaan met de uitwisseling van monsters, maar nu met het doel meetmethoden te ontwikkelen en te toetsen.

LITERATURE

BATE-SMITH, E.G., J.G. HUGHES and T. SWAIN
(1958) After cooking discoloration in potatoes. Chem. and Ind. 627–628.

BETTELHEIM, F.C. and C. STERLING
(1955a) Factors associated with potato texture. I. Specific gravity and starch content. Food Research **20**, 71–80.

BETTELHEIM, F.C. and C. STERLING
(1955b) Factors associated with potato texture. II. Pectic substances. Food Research **20**, 118–129.

BEWELL, E.R.
(1937) The determination of the cooking quality of potatoes. Am. Pot. J. **14**, 235–242.

BILHAM, P., A.E. MAUNSELL and L.H. LAMPITT
(1937) A photometric method for the determination of the colour of cooked potatoes. J. Soc. Chem. Ind. **56**, 165–168.

BOUMA, P.J.
(1946) Kleuren en Kleurindrukken. Meulenhoff en Co, Amsterdam, 320 pp.

BRIANT, A.M., C.J. PERSONIUS and E.G. CASSEL
(1945) Physical properties of starch from potatoes of different culinary quality. Food Research **10**, 437–444.

CHILD, A.M. and J.J. WILLAMAN
(1929) Culinary quality in potatoes. Am. Pot. J. **6**, 259–266.

CLAGETT, W.E. and C.O. CLAGETT
(1941) Polyphenolase activity as the primary cause in darkening of boiled potatoes. Science **94**, 497.

CULLEN, J.C.
(1960) Texture in cooked potatoes. Soc. Chem. Ind. Monograph **7**, 128–134.

FRIELE, L.F.C.
(1954) Kleur en kleurbeoordeling bij „daglicht". T.N.O.-Nieuws **9**, 307–311.

FRIELE, L.F.C.
(1956) De ontwikkeling van de kleurmeting en haar toepassing. T.N.O.-Nieuws **11**, 345–350.

FRIELE, L.F.C. en H.J. SELLING
(1947) Het meten van kleuren II. Beschrijving van de grondslagen der spectrofotometrische meettechniek. Ned. Vezelinst. T.N.O. 75[II] (22 pp.)

GUILD, J.
(1931) The colorimetric properties of the spectrum. Phil. Trans. Roy. Soc. (London) A 230, 149.

HANNING, F. and M.L. HUNSADER
(1957) Problems involved in pretesting the tendency of potatoes to darken after cooking. Am. Pot. J. **34**, 347–358.

HANSEN, F.
(1935) Aarsagerne till Kartoflers Mørkfarvning ved Henstand efter Kogning. Kgl. Danske Landhusholdingsselskab.

HEINZE, P. H., M. E. KIRKPATRICK and E. F. DOCHTERMAN
(1954) Cooking quality and compositional factors of potatoes of different varieties from several commercial locations. Un. St. Dep. Agr. Tech. Bull. 1106 (69 pp).

HESTER, E. E. and G. BENNET
(1956) Quality of pressure-cooked potatoes. Am. Pot. J. **33**, 155–160.

JUDD, D. B.
(1952) Color in science, business and industry. J. Wiley Sons, Inc. New York; Chapman and Hall, London (401 pp.)

JUUL, F.
(1949) Studier over Kartoflens mørkfarving efter Kogning. I Kommission hos. Jul. Gjellerups Forlag. Kopenhagen (152 pp.).

KELLER, E. R. and ST. BÉRCES
(1961) Zusammenhänge innerhalb der für die Qualitätsprüfung benutzten Kriterien. Proc. First Trienn. Conf. of the Eur. Ass. Pot. Res. 323–324.

KELLY, K. L.
(1940) Instructions for determining the color names for drugs and chemicals. Bull. Nat. Formulatory Comm. Am. Pharm. Assoc. **8**, 359.

KUHN, G., N. W. DESROSIER and G. AMMERMAN
(1959) Relation of chemical composition and some physical properties to potato texture. Food Technology **13**, 183–185.

LUGT, C.
(1961) Results of the assessment of the cooking quality of internationally exchanged potato samples. Proc. First Trienn. Conf. Eur. Ass. Pot. Res. 321–323.

LUGT, C. and G. GOODIJK
(1958) Report on the second international meeting of experts in the field of potato quality research, held at Wageningen, Holland, february 3rd, 4th, and 5th, 1958. Versl. no 10 Inst. Biol. en Scheik. Ond. van Landbouwgewassen.

LUGT, C. and G. GOODIJK
(1959) Report on the third meeting of the working group "Potato Quality Research" of the European Association for Potato Research held at Zürich, Switzerland, february, 5th, 6th and 7th, 1959. Versl. no 15 Inst. Biol. en Scheik. Onderz. van Landbouwgewassen.

NICKERSON, D.
(1946) Color measurement and its application to the grading of agricultural products (A handbook on the method of discolorimetry). Un. St. Dep. Agr. Misc. Publ. 580 (62 pp.).

POTTER, A. L. and E. A. MCCOMB
(1957) Carbohydrate composition of potatoes. Pectin content. Am. Pot. J. **34**, 342–347.

SCHIPPERS, P. A.
(1961) The influence of nitrogen and potassium fertilization on the cooking quality of potatoes. Eur. Pot. J. **4**, 224–242.

SCHIPPERS, P. A.
(1963a) The relation between length of growing period and cooking quality of potatoes. Eur. Pot. J. (in press).

SCHIPPERS, P. A.
(1963b) The importance of sampling for the quality research of cooked potatoes. Eur. Pot. J. (in press).

SCHIPPERS, P. A.
(1963c) (Data of experimental fields in 1961). (in press.).

SELLING, H. J.
(1946) Het meten van kleuren. I. Overzicht van en beschouwing over het I.C.I.-kleur-specificatiesysteem. Med. Vezelinst. T.N.O. 75[I] (50 pp.).

SHARMA, M. K., D. R. ISLEIB and S. T. DEXTER
(1958) Specific gravity of different zones within potato tubers. Am. Pot. J. **35**, 784–788.

SHARMA, M. K., D. R. ISLEIB and S. T. DEXTER
(1959) The influence of specific gravity and chemical composition on hardness of potato tubers after cooking. Am. Pot. J. **36**, 105–112.

SHEWFELT, A. L., D. R. BROWN and K. D. TROOP
(1955) The relationship of mealiness in cooked potatoes to certain microscopic observations of the raw and cooked product. Can. J. Agr. Sci. **35**, 513–517.

SMITH, O., L. B. NASH and A. L. DITTMAN
(1942) Potato quality VI. Relation of temperature and other factors to blackening of boiled potatoes. Am. Pot. J. **19**, 229.

SMITH, O. and W. C. KELLY
(1944) Potato Quality VII. Changes in potato tubers following teatments which affect blackening. Proc. Am. Soc. Hort. Sci. **44**, 384.

SMITH, O. and C. O. DAVIS
(1962a) Potato quality XIII. Preventing after-cooking discoloration in oil blanched French fries. Am. Pot. J. **39**, 45–56.

SMITH, O. and C. O. DAVIS
(1962b) Potato quality XIV. Prevention of graying in dehydrated potato products. Am. Pot. J. **39**, 135–148.

SWEETMAN, M. D.
(1936) Factors affecting the cooking quality of potatoes. Maine Agr. Exp. Sta. Bull. 382 (92 pp.).

UNRAU, A. M. and R. E. NYLUND
(1957) The relation of physical properties and chemical composition to mealiness in the potato. I. Physical properties. Am. Pot. J. **34**, 245–253.

WRIGHT, W. D.
(1928–1929) A re-determination of the trichromatic coefficients of the spectral colors. Trans. Optical Soc. (London) **30**, 141.

YOUNG, D. A.
(1962) The selection of potato samples for the evaluation of culinary quality. Am. Pot. J. **39**, 14–18.