GROWTH, RIPENING AND STORAGE OF TOMATO FRUITS

N. Stenvers

PROEFSCHRIFT
TER VERKRIJGING VAN DE GRAAD
VAN DOCTOR IN DE LANDBOUWWETENSCHAPPEN,
OP GEZAG VAN DE RECTOR MAGNIFICUS,
DR. IR. J.P.H. VAN DER WANT,
HOOGLERAAR IN DE VIROLOGIE,
IN HET OPENBAAR TE VERDEDIGEN OP
VRIJDAG 20 FEBRUARI 1976 DES NAMIDDAGS OM VIER UUR
IN DE AULA VAN DE LANDBOUWHOGESCHOOL TE WAGENINGEN

Dit proefschrift met stellingen van
NICOLAAS STENVERS,
landbouwkundig ingenieur, geboren te
Djokjakarta (Indonesië) op 8 december 1922,
is goedgekeurd door de promotor
Dr. J. Bruinsma, hoogleraar in de planten-
fysiologie aan de Landbouwhogeschool.

De Rector Magnificus van de Landbouwhogeschool,

Wageningen, 10 december 1975 J.P.H. van der Want

C

Stellingen

I

Voor een goede kwaliteit en houdbaarheid moeten tomaten in een ver gevorderd kleurstadium worden geplukt.

Dit proefschrift, IV.

II

Tomaten kunnen, onafhankelijk van de weersomstandigheden, gedurende de gehele dag worden geplukt.

Dit proefschrift, IV.

III

Het effect van de bewaring onder verlaagde atmosferische spanning is in de eerste plaats toe te schrijven aan de verlaging van de partiële zuurstofspanning en niet aan de verlaging van de inwendige ethyleen concentratie.

Stenvers, N. en Bruinsma, J. Nature, 253, 532-533.

IV

Door de grote keuze van het heden ten dage aangeboden fruitassortiment is het voor de handhaving van de positie van het Nederlandse fruit noodzakelijk van een maximale op een optimale bewaarduur over te schakelen.

V

De huidige kwaliteitsnormen, welke de consumenten aan land- en tuinbouwprodukten stellen, hebben tot konsekwentie dat de, eveneens door hen gestelde, eisen tot verbetering van de milieuhygiëne in deze bedrijfstakken afgeremd worden.

VI

De kwaliteitskeur op de veilingen is geen maatstaf van de consumptiekwaliteit, maar veeleer een appreciatie van het uiterlijk van de produkten op het moment van aanvoer.

VII

Indien het natuurlijk tekort aan zuurgehalte van, tot appelmoes te verwerken, appels daartoe aanleiding zou geven is het gewenst wettelijk de toevoeging van enig voedingszuur toe te staan.

Driessen, C.P.M. Voedingsmiddelentechnologie, 8, 1-2.

VIII

Het werk van Huelin en Anet over de toxische werking van de geoxydeerde ontledingsprodukten van α-farneseen geeft nog geen volledig beeld van de oorzaak van het ontstaan van de bewaarziekte scald bij appels.

Huelin, F.E. and Murray, K.E. Nature 210, 1260-1261
Anet, E.F.L.J., J. Sci. Fd. Agric. 23, 605-608.

IX

De naar versobering strevende levensstijl, zoals die door de kerken en andere groeperingen wordt voorgestaan, houdt het gevaar in dat ongenuanceerde kritiek wordt uitgeoefend op de behoeften van anderen.

X

De aanduiding door het woord trimmen van, eertijds normale, bezigheden zoals fietsen en wandelen is tekenend voor onze veranderde levensgewoonten.

Proefschrift van N. Stenvers
Wageningen, 20 februari 1976

Inhoud

VOORWOORD

Een van de opdrachten bij het begin van mijn werk in het Sprenger Instituut te Wageningen was het onderzoek naar de invloed van lage temperaturen op de kwaliteit van de geplukte tomaat. Een eenvoudige vraagstelling welke door het uitdiepen van de materie andere interessante aspecten opleverde. Dat hierdoor nieuwe bijdragen konden worden geleverd aan de reeds omvangrijke literatuur over tomaten is mede dank zij de Directeur van het Sprenger Instituut.

Ir. T. van Hiele, in de eerste plaats dank ik u voor de vrijheid die u mij als onderzoeker steeds hebt gelaten en het vertrouwen dat u mij daarmede schonk. In de tweede plaats ben ik u dankbaar voor de gesprekken waarin u mij wees op belangrijke punten voor de voortzetting van het onderzoek.

Hooggeleerde Bruinsma, uw interesse in mijn werk is een grote stimulans geweest voor de voortzetting en de afsluiting van het onderzoek. Zonder uw opbouwende en voortdurende kritiek was deze promotie niet tot stand gekomen. Voor alle energie die u en uw medewerker Dr. Ir. A. Varga in deze eindfase van mijn werk hebben geïnvesteerd ben ik u veel dank verschuldigd.

Vele medewerkers van het Sprenger Instituut hebben bijgedragen tot het welslagen van de proeven. Slechts enkele kan ik hier met name noemen.

Mej. H.W. Stork dank ik voor de wijze waarop zij, door haar grote persoonlijke inzet, de nauwgezetheid bij de uitvoering van de proeven en het verzamelen en uitwerken van het cijfermateriaal, bijgedragen heeft tot het welslagen van het onderzoek.

Door het intensieve contact met Ir. J.W. Rudolphij en zijn medewerker B.J.L. Veltman werden veel technische problemen opgelost.

Drs. O.L. Staden gaf een wezenlijke bijdrage aan het werk door zijn weldoordachte kritiek. De vele gesprekken, welke ik met hem mocht hebben, zijn zeer waardevol geweest voor de vorming van mijn fysiologisch inzicht in de problemen betreffende het geoogste produkt.

Op zeer fraaie wijze heeft O.A. Kühn het fotografisch gedeelte en het tekenwerk van de publikaties verzorgd.

De wiskundige afdeling is steeds actief betrokken geweest bij de opzet van de proeven en de uitwerking van het verkregen cijfermateriaal.

De medewerkers van de chemische en gaschromatografische afdeling hebben het mogelijk gemaakt, dat de vele monsters in korte tijd geanalyseerd konden worden.

De technische afdeling heeft steeds op kundige wijze de benodigde technische installaties verzorgd.

De dames van de typekamer zijn mij met het uitvoeren van het typewerk steeds zeer ter wille geweest.

Buiten het Sprenger Instituut is er steeds een prettige samenwerking geweest met medewerkers van het Proefstation voor de groenteteeld onder glas te Naaldwijk, de Proeftuin Vleuten, het Laboratorium voor Tuinbouwplantenteelt, het voormalige Instituut voor Tuinbouwtechniek en de Technische en Fysische Dienst voor de Landbouw te Wageningen.

Alle medewerkers van het Sprenger Instituut dank ik voor de ondervonden collegialiteit in de afgelopen jaren.

Buiten de werksfeer heb ik veel liefde en geduld ontvangen van mijn vrouw, die mij steeds weer de moed gaf om verder te gaan. De vele uren, die zij en de kinderen hebben moeten afstaan aan de proeven, welke ten grondslag liggen aan dit proefschrift, zal ik nooit vergeten.

ALGEMENE INLEIDING

Ten behoeve van het onderzoek naar het gedrag van de geplukte tomaat onder verschillende temperatuurregimes was het noodzakelijk de rijping van de vrucht te volgen en het rijpheidsstadium op bepaalde momenten te kunnen vaststellen.

Volgens Rhodes (35) is de rijping van vruchten een opeenvolging van veranderingen in kleur, aroma en textuur, welke leidt tot de toestand waarin de vrucht acceptabel is om te eten. Aan deze verschijnselen liggen biochemische veranderingen in de samenstelling en het metabolisme van de vrucht ten grondslag. Het rijp zijn zelf is geen fysiologisch begrip maar een stadium waarin de vrucht consumabel is. Dit stadium is voor iedere vruchtsoort anders.

De rijping kan op verschillende wijzen worden gekarakteriseerd. Het zoeken naar biochemische veranderingen in de vrucht, welke een direct verband hebben met de rijping, behoorde in het kader van de mij opgedragen taak niet tot de mogelijkheden.

De rijping wordt echter ook door twee sensorische eigenschappen gekarakteriseerd, nl. de zachtheid en de kleur. Tijdens het rijpingsproces verandert de kleur van groen in rood, terwijl de zachtheid toeneemt.

Omdat het rijpingsproces geleidelijk verloopt is het volgen ervan alleen mogelijk wanneer het wordt verdeeld in fasen die goed gedefinieerd zijn. Hiertoe leent zich vooral de kleur. Uit een literatuuronderzoek bleek dat er vele kleurschema's gemaakt zijn (3, 12, 30, 33, 40, 45, 47) die variëren van 4 tot 15 verschillende klassen. De omschrijving van deze klassen is vaak onvoldoende vastgelegd waardoor een algemeen gebruik ervan wordt bemoeilijkt.
Er was dus behoefte aan een andere duidelijk omschreven faseninde-ling, waarvan de fysiologische eigenschappen konden worden bepaald.

Ook de zachtheid van de vruchten verandert gedurende de rijping. Naarmate de rijping vordert worden de vruchten zachter.

Wanneer de rijping normaal verloopt gaat de verandering van kleur gepaard aan het zachter worden van de vrucht. De kleur geeft uitwendig een beeld van de rijpheid, terwijl de zachtheid een gevolg is van veranderingen in het vruchtweefsel die gekenmerkt worden door, met de rijping gepaard gaande, ouderdomsverschijnselen. Door oplossing van de pectinen in de celwanden (25) verandert de structuur van de cellen en verliest het weefsel aan stevigheid. Voor een goed inzicht in het voortschrijden van de rijping moeten dus beide parameters terzelfdertijd meermalen aan dezelfde vruchten bepaald worden.

Voor het meten van de hardheid is een instrument nodig. De in de literatuur beschreven hardheidsmeters (1, 6, 7, 14, 22, 23, 24, 26, 27, 31, 38, 39, 44) zijn destructief en dus slechts te gebruiken voor een eenmalige meting. Voor meermalige metingen moet het apparaat non-destructief zijn. Het principe van een dergelijk instrument berust op de mate waarop een plunjer, onder een gegeven gewicht, in de vrucht kan worden gedrukt, zonder dat de elasticiteitsgrens van de schil wordt overschreden. Beschrijvingen ervan worden gegeven door Winsor en Shafshak (39), Hamson (20) en Diener (10). De metingen met deze apparaten zijn echter afhankelijk van de vaardigheid van de gebruiker en daardoor subjectief.

Een voor ons doel geschikte zachtheidsmeter zou aan bepaalde voorwaarden moeten voldoen. Het moet een verplaatsbaar, automatisch werkend instrument zijn voor snelle en betrouwbare metingen van grote monsters vruchten en bovenal non-destructief zijn.

Met behulp van een goed gedefinieerd schema van de kleurveranderingen tijdens het rijpingsproces van tomaten en een geschikte hardheidsmeter is het mogelijk het verloop van de rijping te volgen en de rijpheid op verschillende tijdstippen te karakteriseren. De beoordeling van de invloed van lage temperaturen op het gedrag van de geplukte tomaat was hierdoor mogelijk gemaakt.

De monsters tomaten, gebruikt bij de uitvoering van de proeven, waren soms zeer verschillend van kwaliteit. Het onderzoek werd uitgebreid met het zoeken naar de factoren die de kwaliteit van de vruchten kunnen beïnvloeden.

Verschillende onderzoekers vonden bij tomaten een interactie tussen de vegetatieve plantendelen en de groei van de vruchten. Hun bevindingen zijn echter tegenstrijdig. Murneek en Hemphill (21) en Verkerk (42) vonden bij planten met meer dan het normale aantal van 3 bladen per tros een hogere opbrengst, terwijl bovendien de rijping werd vertraagd. Cooper en zijn medewerkers (8) daarentegen vonden geen verschillen in opbrengst tussen planten met 2, 3 of 5 bladeren per tros. Alleen in het geval dat slechts 1 blad per tros beschikbaar was, was de opbrengst duidelijk lager. Het oogsttijdstip werd echter niet beïnvloed.

Niet alleen het aantal bladeren per tros, maar in het algemeen het beschikbare bladoppervlak per vrucht speelt een rol bij de groei van de vruchten en dus bij de opbrengst. Mogelijkerwijs is er ook een invloed op de kwaliteit van de vruchten.

De groei van tomaten aan de plant is het onderwerp van veel studie geweest. Gustafson (15) en Beadle (5) vonden verschillen in ademhalingsintensiteit, suikergehalte en groeisnelheid tussen verschillende vruchten en verklaarden dit door de verschillende locatie aan de plant. Verschillen in ademhalingsintensiteit kunnen echter ook veroorzaakt worden door een verschil in vruchtgrootte.

Beadle constateerde een afname van de vruchtgrootte aan de tros, naarmate de vruchten verder van de plantenstengel verwijderd zijn. De eerste vrucht zou het eerst bloeien en dus de eerste zijn die profijt trekt van de aanvoer van voedingsstoffen door de plant, waardoor een snellere groei mogelijk wordt. De laatste vruchten aan de tros blijven klein maar rijpen snel wanneer de andere vruchten geplukt zijn. Waarnemingen in de praktijk wijzen er echter op dat het in vele gevallen niet de eerste knop aan de tros is die het eerst bloeit, maar vaak de tweede of zelfs de derde knop. Ook het vruchtgewicht verloopt niet geleidelijk met de plaatsing van de vruchten aan de tros.

Over het pluktijdstip bij tomaten is niets bekend. Over andere vruchten is meer onderzoek verricht. Voor appels is een verband gevonden tussen de rijpheid bij de pluk en het ontstaan van bewaarziekten (18, 46). De aromaontwikkeling tijdens de opslag van appels hangt nauw samen met het pluktijdstip (48). Bij hard fruit is het bepalen van het juiste rijpheidsstadium moeilijk uit te voeren. Bij tomaten is deze bepaling door de duidelijke kleurveranderingen tijdens de rijping gemakkelijker. Bovendien is de opslag van tomaten niet zo langdurig als bij hard fruit. De keuze van het juiste pluktijdstip maakt de opslag van tomaten gedurende een korte periode zeer wel mogelijk.

Twee factoren hebben een grote invloed op de kwaliteit van de tomaat na de pluk.

In de eerste plaats het rijpheidsstadium van de vrucht bij de oogst. Over het algemeen wordt verondersteld dat de groen geplukte vruchten een langere opslagduur kunnen verdragen waardoor het risico van overrijpheid wordt vermeden. Het tegendeel is, blijkens onze onderzoekingen, waar. Groen plukken verhoogt de kans op rotvorming en andere afwijkingen zonder een verminderde kans op overrijpheid ten opzichte van later plukken.

In de tweede plaats spelen de omstandigheden tijdens de opslag een grote rol. De temperatuur is van deze de belangrijkste. Lage temperaturen verlengen de opslag van vruchten. In de literatuur worden temperaturen van 12°C tot 20°C genoemd, welke optimaal zijn voor de opslag en het vervoer van tomaten (4, 9, 11, 19, 28, 29, 34, 36, 41, 43). Deze temperaturen gelden voor tomaten die niet in kassen zijn geteeld. Omdat in Nederland uitsluitend kastomaten worden geteeld moeten deze gegevens geverifieerd worden.

Een hoge luchtvochtigheid bevordert de rijping van tomaten (13, 16, 17). De vraag is of een lage luchtvochtigheid de opslagduur niet verhoogt.

De gegevens over de CA-bewaring van tomaten variëren sterk, waarschijnlijk ook beïnvloed door de teeltomstandigheden in de verschillende landen. De opslagcondities wisselen van 0% CO_2 en 3% O_2 (2, 32, 37) tot 5% CO_2 en 1% O_2 (13, 16).

Over de tijdsduur van de opslag zijn zeer verschillende cijfers bekend. De nieuwste ontwikkeling op het gebied van bewaring van groente en fruit is de bewaring onder verlaagde atmosferische druk. De vraag rijst of deze bewaring voor tomaten geëigend is en een verlenging van de bewaarduur zou kunnen geven.

DOEL VAN HET ONDERZOEK

Het doel van het onderzoek was het bestuderen van de invloed van lage temperaturen op de kwaliteit van de geplukte tomaat.

Voor dit onderzoek was het noodzakelijk om de rijpheid van de vruchten tijdens de opslag te kunnen karakteriseren. Hiervoor waren nodig een non-destructieve zachtheidsmeter en een goed gedefinieerd kleurenschema.

In de loop van de experimenten bleek het noodzakelijk dieper op enkele problemen in te gaan en werd dit temperatuuronderzoek uitgebreid met het onderzoek naar de invloed van vegetatieve plantendelen op de ontwikkeling van de tomaat.

Van vruchten is het plukstadium bepalend voor de kwaliteit na de pluk. Van tomaten was hiervan niets bekend, daarom werd het in het onderzoek betrokken.

Tenslotte werd gezocht naar omstandigheden van opslag, waarbij de kwaliteit van de geoogste tomaat behouden bleef.

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Summary

A non-destructive, automated, fast and portable softness measuring device is described. The non-destructivity of the meter was established.

Factors that might influence the variation in softness-readings, e.g., temperature, relative humidity, the point of compression on the fruit, sampling in the greenhouse, and fruit size were experimentally investigated.

It was concluded that, although all these factors influence the dispersion of the softness readings, the individual tomato fruit by its own qualities causes the greatest dispersion. The developed meter therefore is a useful tool for comparative softness measurements of tomatoes.

Zusammenfassung

Es wird ein nicht-destruktiver, automatischer, tragbarer Härtemesser beschrieben. Die Non-Destruktivität des Apparats wurde gezeigt. Faktoren, die die Streuung der Härtemessungen beeinflussen können, wie z. B. Temperatur, relative Feuchtigkeit, Stelle der Messung auf der Frucht, strenge Selektion der zu erntenden Früchte und Fruchtgröße, wurden experimentell untersucht.

Es wurde festgestellt, daß die genannten Faktoren einen gewissen Einfluß auf die Streuung der Härtemeßwerte haben können, daß jedoch die einzelne Frucht durch ihre individuellen Eigenschaften die größte Streuung bedingt.

Der Härtemesser ist also ein sehr brauchbares Gerät für vergleichende Strukturanalysen bei Tomaten.

Introduction

In the past decades many research workers designed instruments for determining the firmness of fruits, *e.g.* tomatoes. The type of instruments to be used largely depends on the purpose of the firmness determination. If the firmness is important at a given moment only, destructive instruments may be used. The best known of these is the punch-testing machine of *Magness-Taylor* (1, 24, 25, 26), later revised by *Schomer* and *Olsen* (29, 30) and named the mechanical thumb. Other instruments are described by *Médas* (25), *Bourne* (4, 5, 6), *Holt* (18), *Johannessen* (19), *Voisey* and *Lyall* (3), *Mohsenin* et al. (26), *Kattan* (20, 21), *Garrett* et al. (12), *Kramer* et al. (7, 22) and *Ahmed* et al. (1, 2).

Non-destructive instruments must be used when firmness is measured more than once on the same fruits for instance to follow the course of softening during ripening in storage. The principle is a measurement of the displacement of a plunger into the fruit under a given load. Descriptions are given by *Shafshak* and *Winsor* (31), *Hamson* (16, 17) and *Diener* et al. (8, 9). The readings of these instruments are more or less dependable on the skill of the operator and therefore are subjective. Vibration techniques are being used by *Finney* (10, 11) at the USDA Research Laboratory at Beltsville, with promising results.

Softness is a measure for ripeness and is closely related to texture. It is also used to a certain extent for evaluation of quality. Consumers for instance use their hands to test the softness and the quality of the fruits at the same time. If fruits are of a good quality then colour and softness go hand in hand. However, a lot with a reasonable colour can be too soft to be of a good quality. So measurement of softness gives data for quality, additional to those obtained by colour determination. For a determination of the stages of ripening the following classification of colour stages was made which is used in this paper.

Table 1

Classification of colour changes during ripening

Klassifikation der Farbänderungen während des Reifens

Class	Colour	Description
1	100% green	mature green
2	99–95% green, 1–5% orange yellow	turning point
3	75% green, 25% orange	turning phase
4	50% green, 50% orange	
5	25% green, 75% orange	
6	100% orange	table ripe
7	100% bright red, firm	
8	100% dark red, soft	

In a next publication some physiological properties of these colour stages will be analysed.

The behaviour of tomatoes stored under different conditions is one of the projects in study at our laboratories. In order to be able to relate colour stage and firmness a softness meter used for this purpose has to have some definite specifications. It has to be a portable, automated device for quick and accurate determination of large samples and above all, completely non-destructive for repeated observations during the course of ripening.

On these principles the following softness meter for tomatoes has been constructed at the Sprenger Institute (27, 28).

Construction and operation of the softness meter

For the purpose of our experiments, softness is defined as a measure for the giving in of the skin to mechanical deformation without skin rupture. This deformation is exerted by a stamp pressed on the fruit under a given load during a given time. For details of the instrument see figures 1 and 2.

Since the speed of the stamp when pressed on the fruit declines asymptotically, the displacement has to be measured after a certain time, controlled by a clock. After this interval the stamp is arrested and the displacement on the micrometer can be read. At sufficiently short intervals the displacement remains within the limits of skin elasticity. The speed of the stamp when it touches the fruit has to be well defined and should preferably have the value of 0 m/sec. Automation is not only desirable to meet this requirement but, moreover, enhances the reproducibility and speed of the operation. The meter has a capacity of 3 readings per minute.

A fruit to be measured is put on the support table q with the blossom end up; a three point support is chosen after *Boeke* (3).

Measuring starts by pressing a pedal and the table is screwed up by the motor in g. The excentric causing this movement is so constructed that the speed is constant. In the center of the stamp o is a trigger pin p. During the movement of the table there is ample time to place this pin p on the exact point of measuring, preferably the stylar scar.

When the pin p is pushed entirely back into the stamp by the ascending fruit, a system is triggered which both stops the driving motor g and releases the stamp simultaneously. Up till then stamp o is kept in place by means of an electro-magnet t. The free fall of the stamp and the impact speed can be adjusted by pin p. If this pin is not permitted to enter the stamp entirely the release of the stamp causes a free fall and, therefore, an impact speed. By changing the length of the pin entering the stamp the free fall and the impact speed can be varied. Concomittant with the release of the stamp, a clock h is started which halts the stamp after a pre-set time by means of a brake system. The deformation can then be read from the displacement reader b in 0.01 mm units.

The starting position can be re-established by pressing button f. The table lowers automatically and the stamp moves upwards by force of the electro-magnet c. Then the measurement proceeding can start again.

Results

Variation in softness readings as a consequence of the construction of the meter

Analysis of the deviation of the meter

On the scale of the micrometer a deviation by reading of 0.005 mm is possible. To find the actual deviation of the meter, measurements were carried out on solid materials. The frequency distributions as given in table 2 show a normal distribution of the readings well within 0.1 mm.

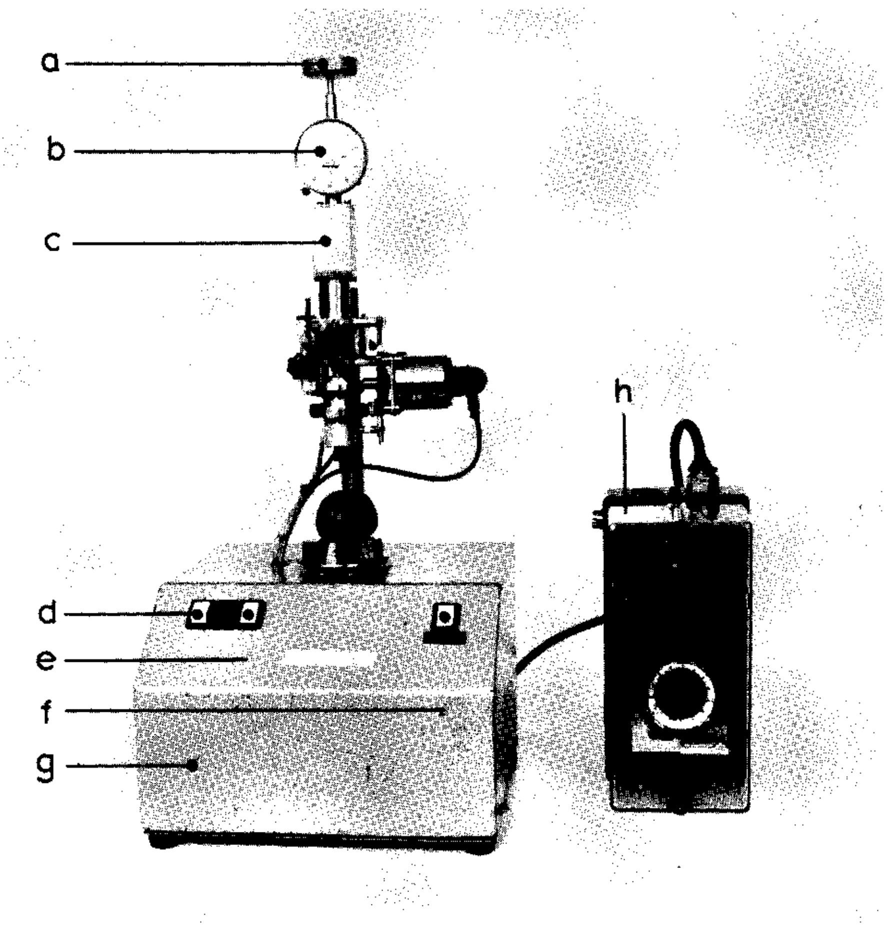

Fig. 1: The softness meter for tomatoes, constructed at the Sprenger Institute Wageningen
Der Härtemesser für Tomaten, konstruiert im Sprenger Institut, Wageningen

Legend of figures 1 and 2

a. Platform for placing weights
b. Micrometer in 0.01 mm (displacement reader)
c. Electro-magnet for holding and releasing the stamp (o)
d. On/off switch
e. Push button to start the measurement, later replaced by a pedal
f. Push button for the stamp to resume starting position
g. Motor drive system
h. Timer

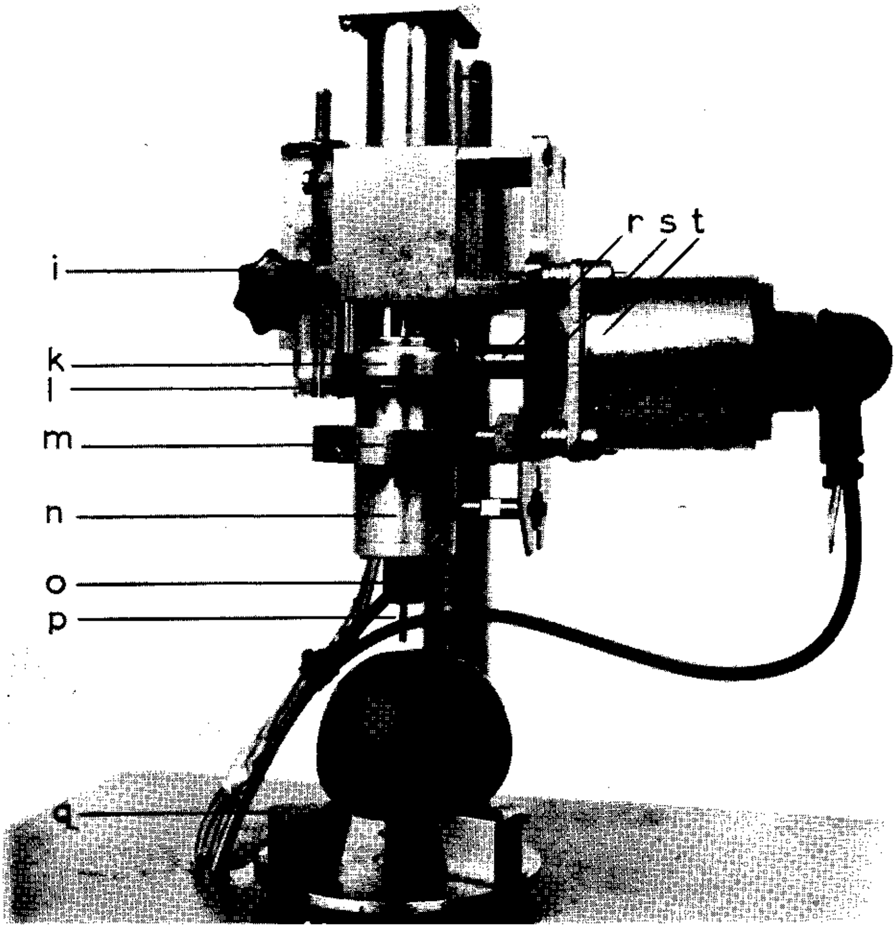

Fig. 2: Some details of the softness meter
Einige Einzelheiten des Härtemessers

i. Adjustment knob for magnetic field switch 1
k. Brake
l. Magnetic field switch for trigger pin p
m. Trigger ring
n. Housing
o. Stamp
p. Trigger pin
q. Three point support
r. Brake pin
s. Brake pin release spring
t. Electro-magnet to activate brake system

Table 2

Frequency distribution of softness readings, in mm, on solid materials

Häufigkeitsverteilung der Härtemeßwerte bei harten Materialien

Load 300 g, time 5 sec,

free fall 0.1 mm				free fall 3.5 mm	
rubber ball		steel plate		steel plate	
mm	frequency	mm	frequency	mm	frequency
0.90	15	0.11	3	3.45	19
0.91	108	0.12	12	3.46	1
0.92	21	0.13	14	3.47	11
0.93	6	0.14	94	3.48	5
		0.15	25	3.49	90
		0.16	2	3.50	16
				3.51	6
				3.52	2
total	150		150		150

The tip of the stamp

The shape of the stamp tip plays an important role in the height and the dispersion of the readings of a sample of fruits. Some authors use a flat tip (28), others a slightly convex one (8, 29). In preliminary experiments the flat tip gave such a variation in readings that it was abandoned. The experiments were carried out with a convex and a pointed tip of the stamp. 'Moneymaker' fruits in different colour stages were stored immediately after picking at 10 °C and 19 °C and a relative humidity of 70 and 87%. Softness measurements were made every 24 hours. Table 3 gives the variance S^2 of the softness measurements with both stamp tips during storage under various conditions.

Table 3

Variance S^2 of the softness measurements of two stamp tips during nine days of storage of different colour stages under various conditions

Varianz S^2 der Härtemeßwerte von zwei Stempeln während neuntägiger Aufbewahrung verschiedener Farbklassen unter verschiedenen Bedingungen

	Storage conditions					
stamp tip \ colour stages	10 °C r. h. 70%	10 °C r. h. 87%	19 °C r. h. 87%			
	5	5	1	3	5	6
pointed	225.9	88.0	1084.2	212.4	732.2	663.4
convex	73.8	39.9	151.6	216.9	567.7	413.7

It is obvious that the convex stamp tip gives the smallest variance in readings. Therefore this stamp tip was chosen for further experimental work.

Influence of compression time and weight combinations on the softness readings

The best combination of compression time and weight is the combination which differentiates best between the different stages of ripeness.

Therefore, three experiments were carried out with combinations of varying compression periods and plunger weights. Table 4 gives the results of the experiment with 'Moneymaker' fruits. The experiments with 'Extase' fruits gave similar results.

Table 4

Mean softness readings of different colour stages of 'Moneymaker' fruits, 10 fruits per sample

Time 5 sec, free fall 0.1 mm, readings in 0.01 mm units

Mittlere Härtemeßwerte der verschiedenen Farbklassen der Sorte 'Moneymaker', 10 Früchte je Stichprobe

Time in sec	Load (g)	200				250				300				350			
	Colour stage	3	4	5	6	3	4	5	6	3	4	5	6	3	4	5	6
5		54	63	73	90	63	72	89	104	84	96	116	138	99	122	137	165
10		64	74	79	94	77	86	98	114	86	97	126	147	112	126	149	181
30		68	71	87	95	77	97	101	125	95	106	121	141	107	119	155	187
60		67	69	92	105	84	93	111	133	93	121	132	156	112	126	149	175

The standard deviation, on an average, varied from 5.7 to 27.7 irrespective of weight load or compression time.

Statistical analysis shows marked differences between the readings of the 200 g and the 250 g load, the latter giving more reliable differences in firmness between the colour stages, independent of the compression time.

A small difference between the 250 g and the 300 g loads is in favour of the latter, especially at the short time readings. The 300 g load gave slightly better results than the 350 g load. Whereas a heavier load unvariably gave higher readings, this was not always the case with a longer compression time, owing to the elasticity of the fruits. Short time measurements are therefore to be preferred.

According to the demands set for the firmness readings, such as non-destructivity, swiftness and the best reproducible statistical differences, the combination of a 300 g load and a compression time of 5 sec turned out to be optimum.

Non-destructivity of the meter

Avoiding injury is the paramount requirement of the meter because of the storage experiments to be carried out. Several experiments were conducted to test this non-destructivity. In one, series of 20 individual 'Moneymaker' fruits were measured 25 times successively on the stylar scar with a 300 g load and a compression time of 5 sec. A typical example of the results is presented in fig. 3.

The variations are not due to damage but are to be ascribed completely to such factors as deviation in readings and coincidental differences, the dispersion of the readings being within the range of the meter itself.

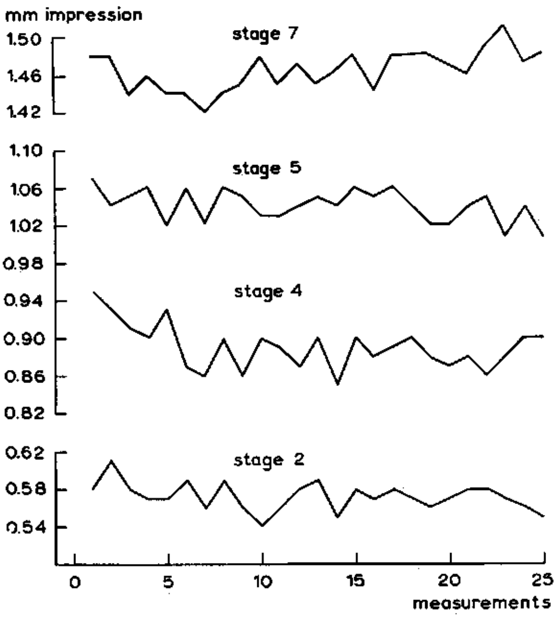

Fig. 3: Softness readings of tomato fruits of different colour stages, compressed 25 times successively at the stylar scar

Härtemeßwerte von Tomaten verschiedener Farbklassen, 25mal hintereinander belastet auf der Blütenseite

Other series of 25 tomatoes, variety 'Delcro', of different colour stages (4 and 6) were measured individually, 25 times subsequently, but now 3 times per day. None of the differences between readings of the same sample are statistically significant.

Table 5

Softness readings of samples of 25 fruits each, measured 25 times subsequently, 3 times per day, at 1 or 2 hrs intervals. Load 300 g, time 5 sec, free fall 0.1 mm, readings in 0.01 mm units

Härtemeßwerte der Stichproben von 25 Früchten, 25mal nacheinander gemessen, dreimal täglich nach 1 oder 2 Stunden

Colour stage	time of measurement	mean softness	mean error of the mean softness
4	9.00 a.m.	118.0	3.67
	10.00 a.m.	120.0	3.30
	11.00 a.m.	113.6	3.52
4	9.00 a.m.	98.3	2.58
	11.00 a.m.	98.8	2.88
	13.00 p.m.	96.5	2.60
6	9.00 a.m.	169.7	6.99
	10.00 a.m.	162.4	6.28
6	11.00 a.m.	162.4	7.20
	9.00 a.m.	156.0	5.37
	11.00 a.m.	156.3	5.14
	13.00 p.m.	148.9	4.75

Experiments in which samples of 25 fruits were tested each day, or every second, third, fourth day or once a week, showed no significant differences in firmness readings after 3 weeks.

The conclusion can be drawn, therefore, that tomatoes tested with this meter are not damaged even over a prolonged period.

Influence of the place of compression on the fruit

Different readings are likely to be obtained at different places on the fruit surface, reproducible and comparable readings requiring an unequivocal position determination. *Shafshak* and *Winsor* (31) measured the compression on the stylar scar, *Sobotka* et al. (8, 9) and *Hamson* (16) positioned the fruit by placing it on its side and measured the firmness with the plunger contacting the fruit at its greatest diameter. *Hamson* (16) found the compression readings with the plunger over the radial walls to be significantly smaller than those with the plunger over the locules.

In samples of 20 fruits of the same colour readings were compared at the stylar scar, and over the locules and radial walls at the largest diameter of the fruits. The readings at the stylar scar and at the radial walls differed from those at the locules at the 99% level. Changing the compression place on the radial walls or on the locules, however, gave variations in readings. Therefore, samples of 20 fruits were again measured at fixed points over the radial walls and the locules as presented in fig. 4. Lines were drawn from the calyx through the stylar scar right over the middles of the locules and along the radial walls. The four lines were each divided into 4 parts of equal length.

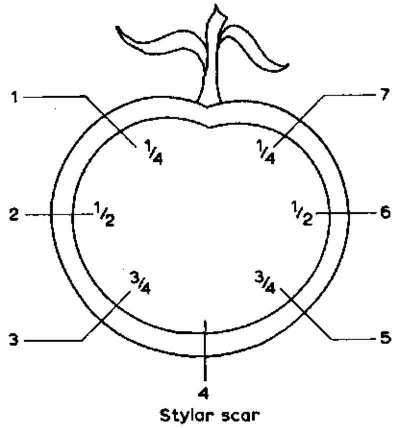

Fig. 4: Diagram of the measuring points on the fruit surface
Schema der Meßpunkte auf der Fruchtoberfläche

Fig. 5 shows how softness increases from the calyx to the stylar scar end. From colour stage 1 to 4, the increase was continuous both at the radial walls and at the locules, the stylar scar side of the fruit being always the softest. This confirms that ripening of the tomato starts at the blossom end.

As ripening advances firmness further declines, the stylar scar now remaining firmer than the sides over the locules. Softness and ripening both advance from the blossom end to the calyx end. When the fruits are table-ripe, the readings at the stylar scar and the calyx end on the locules are equal. The readings on the radial walls are still lower on the calyx end. Statistical analysis of the data shows that differences in variance occur between the readings at different places on the fruits. However, no point has consistently less variance than the others in the *Friedman* test.

Because of these differences in readings on the sides of the fruits it is clear that measuring softness on a well-determined point is the only way for comparisons. Although the differences in the course of ripening are maximum at the sides of the fruits, because of its distinction the stylar scar was chosen as the appropriate position to measure fruit softness in the best reproducible way.

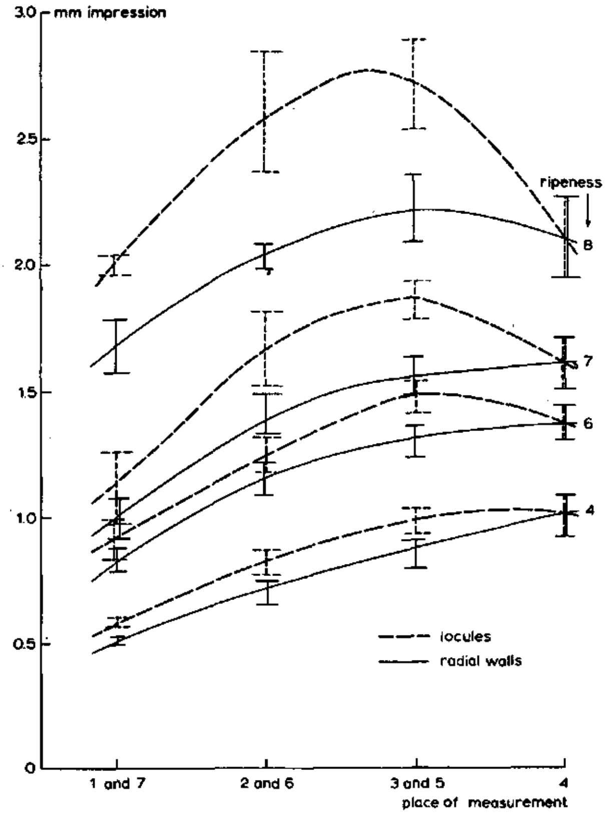

Fig. 5: Mean softness readings at different points on the fruit surface according to figure 4
Mittlere Härtemeßwerte der Punkte auf der Fruchtoberfläche wie angegeben in Abb. 4

Influence of temperature and relative humidity

It is well known that temperature and relative humidity (r. h.) during storage play an important role in the ripening process (14, 15, 32, 34). Favourable conditions are 20 °C and r.h. of 85–92%. This combination stimulates ripening, but also contamination by micro-organisms. Reducing the r.h. reduces the attack of fungi but increases loss of water by transpiration, hence the fruit firmness declines. These effects become visible and also measurable after a few days.

'Moneymaker' fruits, picked at random in colour stage 4, stored at 19 °C and a r.h. of 87%, showed no difference in softness readings when measured directly or after cooling to 15 °C, measurements being taken every other day during a fortnight. Similarly, it made no difference whether fruits, stored at 10 °C, were warmed up to 14 °C or not before measurement.

Influence of fruit size

Diener et al. (8) found correlations between fruit size and firmness of 0.10 and 0.15 for the Pressure Load Meter and the Instron Universal Testing Instrument respectively. *Hamson* (16) found correlations of – 0.096 and – 0.036 between fruit size and firmness of two selections. *Shafshak* and *Winsor* (31) also found no significant correlations between compression readings and the size of the individual fruits.

To verify these findings 'Moneymaker' fruits of the size 47/57 mm were divided in the groups: size 47/48, 52/53 and 56/57 mm. The colour stages 3 and 5 of the fruits were carefully selected. Each sample consisted of 50 fruits for the first and 40 for the second experiment.

Table 6

Softness readings of differently sized 'Moneymaker' fruits. Load 300 g, time 5 sec, free fall 0.1 mm, readings in 0.01 mm units

Härtemeßwerte von Tomaten verschiedener Größe

Fruit size		Experiment I Colour stage 3	Experiment I Colour stage 5	Experiment II Colour stage 3	Experiment II Colour stage 5
47—48 mm	$\bar{x}$	78.9	120.0	76.0	118.3
	S	9.6	17.7	11.4	14.8
52—53 mm	$\bar{x}$	79.0	118.0	75.4	119.2
	S	8.2	19.4	9.7	17.3
56—57 mm	$\bar{x}$	76.0	113.8	71.8	117.9
	S	8.0	15.1	8.3	21.5

$\bar{x}$ = mean of 50 and 40 readings respectively.
S = standard deviation.

Table 6 shows that there were no significant differences in the readings of fruits of different sizes.

In other experiments samples of 50 'Moneymaker' fruits, picked in colour stage 5, consisting of fruits of 46 to 47 mm and larger than 57 mm were carefully selected and stored at 19 °C and a relative humidity of 87% during 13 consecutive days. Firmness readings were made every day.

As shown in table 7 there were no significant differences between the softness readings on the same days. These data confirm the findings of other research workers that fruit size does not interfere with the determination of firmness.

Table 7

Softness readings during storage of 'Moneymaker' fruits at 19 °C and a r. h. of 87%
Load 300 g, time 5 sec, free fall 0.1 mm, readings in 0.01 mm

Härtemeßwerte während der Aufbewahrung von 'Moneymaker' Tomaten bei 19 °C und einer r. F. von 87% in zwei Versuchen

Day of measurement	Size (mm)	Experiment I $\bar{x}$	Experiment I S	Experiment II $\bar{x}$	Experiment II S
1	46—47	83	6.7	88	9.0
	>57	86	9.8	90	8.8
4	46—47	114	11.1	117	12.6
	>57	109	17.4	114	11.8
7	46—47	136	14.4	136	17.3
	>57	131	19.7	135	16.9
10	46—47	154	14.5	155	18.4
	>57	149	22.1	152	20.2
13	46—47	172	17.0	172	21.7
	>57	177	41.7	175	23.1

$\bar{x}$ = mean of 50 firmness readings
S = standard deviation

Influence of sampling

To reduce the variation in samples, some authors (23) recommend to leave only a few fruits, *e.g.* 4 to 5, on a plant or cluster, to obtain fruits of the same size, weight and physiological age.

In the experiments on the influence of temperature and humidity (p. 527), samples were included which were picked from the fifth truss, second place from the stem only. Colour and size were practically identical. Comparing softness measurements of these samples with at random picked samples gave almost identical data, even when measured daily during a fortnight. Only the dispersion in the case of the carefully selected sample was slightly less than that from the at random picked sample.

It is concluded that selecting a sample very carefully is not really rewarded by a marked improvement of reproducibility of its softness readings.

Discussion

In order to determine softness as a measure of ripeness of tomato fruits, a device has been developed meeting a variety of requirements. Apart from being accurate, fast, easy to handle, and portable, the meter had to give reproducible results without damaging the tissue, in order to enable repeated measurements in the course of the ripening process of individual fruits.

Comparison of data is often hampered by subjective elements entering the measurements with available instruments. In the softness meter described in this paper, these elements are avoided by automation of all operations after placing the fruit in position. This considerably reduces the variation in the readings, a further reduction being obtained by using a slightly convex stamp tip. The meter can be adapted to materials of widely differing firmness by varying the weight of the stamp and the time of compression, both factors being strictly determined and reproducible.

The non-destructivity of the meter was carefully tested and it can be regarded quite safe for tomato fruits. Also for such other materials as bananas in different stages of ripening, the instrument turned out to be a reliable utensil. The temperature and relative humidity of the air during the measurement proved to be no exacting conditions.

A source of inaccuracies is the tomato fruit itself. It was shown that also when softness is taken as a measure of ripening, this process starts at the blossom end and proceeds towards the calyx end. Initially, the stylar scar is the softest place of the fruit, but gradually the compressibility of the sides increases more than that of the scar. Yet, because compression over the radial walls is smaller than that over the locules and, moreover, the softness varies greatly between the blossom and calyx ends, the well-defined stylar scar is considered to be the most unequivocal position on the fruits and, therefore, the appropriate place for reproducible measurements.

Neither the size of the fruit nor the accuracy of sampling interfere with the measurements to any appreciable extent. Variations owing to differences in soil structure, water content, or fertilization could never be established. Occasionally, however, fruit samples of a very homogeneous appearance as to size and colour, showed large variations in softness readings. These are more likely to be ascribed to improper post-harvest treatment than to irregular preharvest conditions. Thus it is the properties of the individual fruit which cause the main variation in the softness readings.

It can be concluded that the designed softness meter meets the requirements for a reliable and convenient following of the ripening of tomato fruits.

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Summary

A scale is presented for the rating of tomato fruit ripening by visual determination of the skin colour in 8 stages. The stages 2 to 7 closely correspond with changes in reflection of fruit homogenates, softness, specific gravity, internal ethylene concentration, and respiration.

The ascorbic acid is mainly confined to the pericarp tissue, its content does not change with ripening.

Zusammenfassung

Angegeben wird eine Skala zur Ermittlung der Entwicklung der Tomatereife durch eine visuelle Bewertung der Schalenfarbe in 8 Stadien. Die Stadien 2 bis 7 stimmen engstens überein mit Änderungen in Lichtreflexion homogenisierter Früchte, Härte, spezifisches Gewicht, der inneren Äthylenkonzentration, und der Atmung.

Das Ascorbinsäuregehalt ist hauptsächlich mit dem Pericarp verbunden und ändert sich nicht während der Reifung.

Introduction

According to Rhodes (11) the ripening of fruits may be defined as the sequence of changes in colour, taste, flavour and texture which leads to the state at which the fruit is acceptable to eat. Underlying these phenomena are various biochemical changes in the composition and metabolism of the fruit. Ripeness as such is not a physiological phenomenon but a state of edibility varying from one type of fruit to another.

The best known sensorial properties of tomatoes are colour and firmness. During ripening the colour of the tomato changes from green to red. Most authors dealing with tomatoes made their own classifications of these colour changes, distinguishing from four to fifteen different stages (Ayres and Peirce (1); Emmert and Southwick (4); McColloch (8); Pratt and Workman (10); Simons (12); Walford (15); Winsor et al.(16).

Ripening is a continuous process. To evaluate the progress of ripening it is necessary to classify the colour development in a number of well defined stages. In this paper a scheme of 8 stages is presented, the physiological properties of which are described.

Experimental

Materials

Several cultivars were used to include varietal differences. Such differences pertain for instance to the measure in which chlorophyll is broken down prior to carotenoid synthesis: "non green back" varieties becoming more pale before ripening than "half green" or "green" cultivars. The last cultivars are mostly dark green coloured at the calyx end, whereas the "non green back" cultivars are always evenly light green coloured.

The fruits were picked in the greenhouse, brought directly to the laboratory and classified according to their colour after Table 1. All determinations were done on freshly harvested fruits.

Table 1 Classification of colour development during ripening
Klassifikation der Farbänderungen während der Reifung

Stage	Description of colour	stage of ripeness
1	100% green, onset of chlorophyll breakdown	mature green
2	99-95% green, 1-5% yellow- orange	turning point
3	95-66% green, 5-34% orange	turning phase
4	66-34% green, 34-66% orange	turning phase
5	1-34% green, 99-66% orange	turning phase
6	100% orange	ripe, edible
7	100% bright red, firm	ripe, edible
8	100% dark-red, soft, still edible	ripe, edible

The mature green stage is difficult to determine exactly so that samples of stage 1 tend to ripen irregularly. Also because the fruits at this stage were found to be susceptible to Botrytis rot, stage 1 was abandoned in most experiments.

The significance of differences between mean values was determined by the t-test.

Methods

The tomato starts colouring at the blossom end, from where the colour spreads to the calyx end. The *colour pattern* over the fruit is uneven, for instance the pericarp over the sides of the locules and over the radial walls colours faster than over the centres of the locules. In colour stage 5 all but the centres of the locules is orange coloured.

Measuring colour locally does not give sufficient information about the colour stage of the whole fruit.

The *reflection of homogenates* of fruits of the different colour stages was measured with the Hunterlab model D-25 Color and Color Difference Meter, after Hall (5,6).

Softness was measured with the non-destructive softness meter described by Stenvers et al. (14). Three cultivars were used. "Moneymaker" and "Maascross" (non-green back), and "Topcross" (green).

Specific gravity was determined according to Mohr. The finding of Nettles (9) that the specific gravity of individual fruits varies considerably was confirmed. Therefore the samples of the different colour stages were taken as large as possible, for cv. Extase (halfgreen) varying from 50 to 80 fruits and for cv. Delcro (non-green back) from 20 to 30 fruits per sample.

Samples of the inner gas phase of submerged fruits were taken with a hypodermic needle at the same depth of 20mm (Knegt et al. 1975). In a sample of 1 ml the *ethylene content* was determined with a gas chromatograph. In these experiments the cultivars Extase and Moneymaker were used in samples of 5 to 10 fruits.

The *CO_2 production* of single fruits was measured in the respirotron as described by Boeke (2). Clendenning (3) stated that the CO_2 production depends on the position of the fruit on the truss and of the truss on the plant. To verify this fruits, cv. Moneymaker, were sampled partly at random and partly carefully from the same place on the same truss.

To determine the *respiratory quotient* (RQ) the CO_2 production and the O_2 uptake were measured with an Orsat gas analyzer using 3 kg fruit samples, cv Moneymaker, stored at 19°C in 21 l desiccators.

Large samples of cv. Moneymaker fruits were taken and divided into pericarp, inner carpel walls, and locular tissue including seeds. In 100 g samples of these fruit parts the *ascorbic acid* content was determined after Zonneveld (17).

Results

The course of the different parameters was determined for the stages of the colour grading scale given in Table 1.

Table 2 presents the results of the colour reflection measurements of fruit homogenates.

Table 2 Reflection of fruit homogenates
Reflexion homogenisierter Früchte

Colour stage	Red reflection		
	Extase		Moneymaker
	I	II	
1	-13.0	-12.1	-
2	- 8.3	-10.4	- 5.4
3	- 5.0	- 5.8	+ 6.7
4	+ 4.0	+ 9.0	+13.5
5	+15.6	+14.5	+16.8
6	+18.0	+19.1	+23.4
7	+21.4	+22.2	-

The result of non-destructive visual determination of skin colour matches that of the instrumental measurement of the homogenate.

Table 3 gives data of softness at different colour stages, the differences between stages being statistically significant at the 95-99% level.

Table 3 Softness at different colour stages
Härte der verschiedenen Farbklassen

Colour stage	Impression at stylar scar in mm		
	"Moneymaker"	"Maascross"	"Topcross"
1	0.47	0.51	0.42
2	0.69	0.79	0.63
3	0.89	0.84	0.81
4	1.00	0.98	1.00
5	1.44	1.13	1.18
6	1.60	1.41	1.33
7	1.81	1.76	1.56

The change in specific gravity during ripening differs considerably in different varieties. For the cv. Extase the differences in specific gravity of fruits at different colour stages (Fig. 1) were highly significant (99:1), except for the stages 5 and 6 in experiment 1. With"Delcro"fruits the colour stages mostly differed significantly in specific gravity (19:1), a selectively composed sample giving no better results than a sample at random.

Fig.1 Specific gravity at different colour stages
Das spezifische Gewicht der Farbklassen

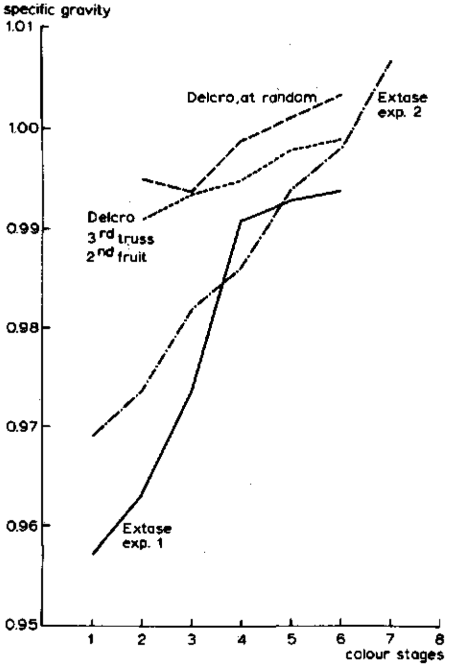
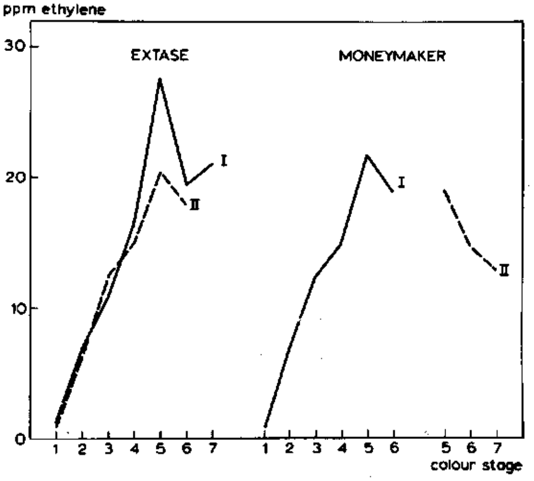


Fig. 2 gives the results of measurements of the internal ethylene concentration. A good relationship between ethylene concentration and colour determination occurs, at colour stage 5 the level of endogenous ethylene is always the highest.

Fig. 2 Internal ethylene concentration in freshly picked samples at different colour stages

Die innere Äthylenkonzentration frisch geernteten Früchten verschiedener Farbklassen



The graph of figure 3 represents the CO_2 production of an individual fruit, at the mature green stage.

Fig. 3 CO_2 production in mg CO_2/h
CO_2 Produktion in Mg CO_2/hStunde

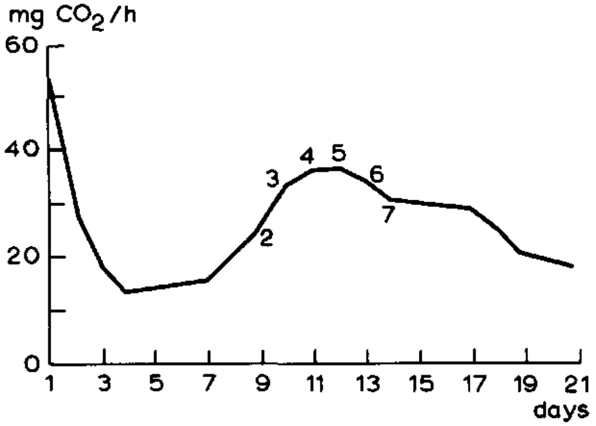
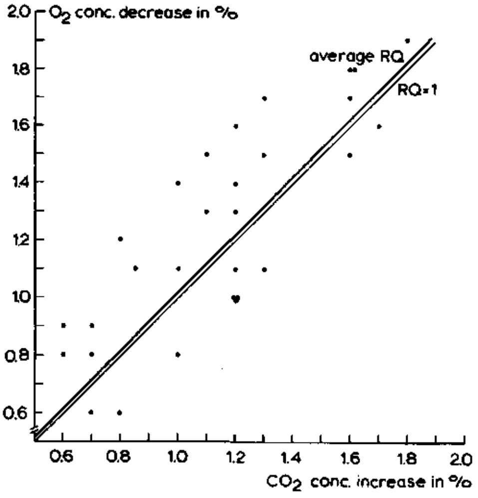


Figure 4 shows that the average R.Q. value of the ripening tomato fruit does not differ significantly from unity

Fig. 4 Dispersion of the R.Q. values
Die Streuung der R.Q. Werte



Unlike in many other fruits, in the tomato no appreciable conversion of organic acids into reducing sugars occurs, so that the carbon dioxide determinations presented in Figure 3 correctly reflect the course of respiration.

Table 4 shows the distribution of ascorbic acid in Moneymaker tomato fruits.

Tabel 4 Distribution of ascorbic acid in "Moneymaker" fruit
Verteilung der Ascorbensäure in "Moneymaker" Fruchte

	mg ascorbic acid per 100 g tissue		
Colour stage	Pericarp	Inner carpel walls	Locular tissue and seeds
1	17.1	2.6	1.5
2	15.7	2.4	2.2
3	14.4	2.5	2.6
4	15.0	3.5	3.5
5	12.5	2.8	2.3
6	12.9	2.3	2.5
7	13.8	3.2	2.0

Table 4 shows the distribution of ascorbic acid in Moneymaker tomato fruits.

With cultivar Extase about half of the ascorbic acid is present in the pericarp. A change in the ascorbic acid content during ripening was never found.

Discussion

In this paper several qualities of tomato fruit ripening are described in connection with a scale of colour development, Reflection of fruit homogenates, increase of softness, specific gravity, and internal ethylene concentration nicely correspond with the colour scale. These factors gradually change during the ripening of the fruit, the ethylene concentration reaching an maximum value at stage 5 about simultaneously with the climacteric peak. It is emphasized that the peak in the climacteric rise could only be established by using single fruits in the respirotron.

Data about the ascorbic acid content of tomato fruits during ripening are conflicting (Salunkhe et al. 1974). A change in ascorbic acid content during ripening in the cultivars used was never established. Ascorbic acid is mainly found in the pericarp tissue.

It can be concluded that the proposed and experimentally used colour classification adequately reflects the ripening process of the tomato fruit.

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Summary

Experiments with tomatoes were carried out to analyse the interaction of fruit growth and fruit:leaf ratio, and of ripening and position of the fruit on the truss.

Different fruit:leaf ratios give different yields. Fruit weight and volume are positively correlated with the leaf area per fruit. Total yield, however, depends mainly on the number of fruits per cluster.

No differences in postharvest quality were found between fruits picked early in the morning and in the afternoon.

A fruit:leaf ratio of 1:3 gives uniform fruits. However, the more leaf area per fruit, the more fruits with greenish coloured locular tissue occur. The seeds in this anomaly coloured tissue are less germinable than those of red-coloured jelly. The ascorbic acid content of fruits with greenish coloured locular tissue is higher than that of normally coloured fruits. The data are consistent with the view that there might be a ripening inhibitor, originating from the leaves and acting also on the physiological condition of the seeds.

For the different positions of fruits in the truss, the morphological and physiological ages did not differ sinificantly. Only in 50-60% of the trusses the fruit nearest to the main stem was the first to be fertilized and to mature. Weight is positively correlated, ripening, however, negatively correlated with the number of seeds.

Unripe fruits detached from the vine, but kept under the same conditions as those on the vine, have hardly the tendency to ripen more rapidly. Therefore the occurence of a ripening inhibiting substance from the foliage is not conclusively demonstrated in tomato.

Zusammenfassung

Versuche mit Tomaten wurden ausgeführt zur Analyse der Wechselwirkung zwischen Fruchtwachstum und dem Frucht - Blatt Verhältnis und der Reife und der Lage der Frucht an der Traube.

Es zeigte sich dasz verschiedene Frucht - Blatt Verhältnisse unterschiedliche Erträge ergeben. Fruchtgewicht und -volumen sind positiv korreliert mit der mittleren Blattoberfläche per Frucht. Der Totalertrag ist hauptsächlich abhängig von der Anzahl der Früchte pro Traube.

Es wurden weder Qualitätsverluste, noch eine Abnahme der Lagerungsfähigkeit festgestellt bei einer Ernte am frühen Morgen und am Nachmittag.

Ein Frucht - Blatt Verhältniss von 1:3 ergibt Früchte gleichmäsziger Form und gleichen Gewichtes. Aber mit zunehmender Blattoberfläche pro Frucht nimmt auch die Anzahl der Früchte mit grüner und deswegen abweichender Lokularmasse zu. Die Samen dieses abweichend gefärbten Gewebes sind weniger keimfähig als diejenigen rot gefärbten Gewebes. Der Ascorbinsäuregehalt der Früchte mit grüner Lokularmasse ist höher als der Gehalt bei den Früchten mit normal gefärbter Lokularmasse. Diese Ergebnisse erhärten die Annahme dasz ein reifungsverzögernder Hemmstoff von den Blättern stammen könnte der ebenfalls die physiologischen Verhältnisse der Samen beeinflusst.

Das morphologische und physiologische Alter der Früchte wies mit bezug auf ihre Lage an der Traube keine wesentlichen Unterschiede auf. Nur bei 50-60% der Trauben wurden die Früchte nächst dem Hauptstengel zuerst befruchtet und reiften eher. Fruchtgewicht und Samenzahl sind positiv, die Reife und Samenzahl jedoch negativ korreliert. Die letzte Tatsache dürfte von einer Hemmung seitens der Samen herrühren. Früchte, gepflückt und aufbewahrt unter gleichen Bedingungen wie nicht gepflückte Früchte, neigen geringfügig zu einem schnelleren Ablauf der Reife.

Das Vorkommen eines aus den Blättern stammenden reifeverzögernden Hemmstoffes ist für Tomaten nicht einwandfrei bewiesen.

Introduction

An interaction between fruit growth and vegetative parts of tomato plants has been established by several research workers.

Murneek and Hemphill (5) and Verkerk (20) found that tomato plants with more than three leaves between trusses produce a higher yield than plants with the normal three leaves and, moreover, the time of harvest was retarded.

Cooper et al. (6), however, were unable to demonstrate significant differences in yield with 2,3 or 5 leaves per truss. Only when one leaf per truss was left the yield was markedly reduced. These authors also found that very severe deleafing reduced the yield of an early crop, earliness itself being not affected.

The growth of tomatoes on the vine has been subject of much experimental work. Gustafson (11) determined the respiratory curves of tomatoes, showing that a climacteric rise occurs simultaneously with the appearance of the red colour of the fruit. Gustafson (12) and Beadle (1) found considerable differences between individual fruits in respiratory intensity, carbonhydrate content, and growth rate. They suggested that the different position of the fruits on the plant is the cause of the differences found.

Beadle observed a decrease in fruit size on passing down the truss from the main axis. The first fruit of the truss has the first claim on the influx of foods into the truss and, therefore, grows faster than the subsequent fruits. The last fruits remain smaller but ripen rapidly after removal of the others and their seeds turn out to be mature. These two facts, in combination with the fact that the flowers on the truss are fertilized in rapid succession, led Beadle to the conclusion that morphological and physiological age are not widely separated.

The present experiments were set up to determine the optimum ratio between numbers of leaves and fruits. At the same time side effects, originating from the different ratios, were studied.

Other experiments were carried out in which ripening on the vine was compared with ripening of fruits picked four and eight days before colouring started and stored under greenhouse conditions.

Experimental

A triplicate experiment with cv. Moneymaker tomato plants was carried out with the following ratios between fruits and leaves: 1:3, 2:3, 3:3, 4:3, 6:3, 6:2, 6:1.

The flowers were pollinated by hand and labelled, trusses with less than 6 flowers were abandoned. When the fruits started to develop, the trusses were reduced to the number of fruits required for the different treatments. The number of leaves was also reduced, no more than three leaves per truss being left. Axillary shoots were removed and the plants were topped after the fifth truss. The fruits were left on the vine until fully orange, then time interval from pollination, weight, volume, internal ethylene concentration, softness (Stenvers et al (18), number of seeds, colour of the locular tissue, and ascorbic acid content were determined.

In two subsequent years experiments were carried out to compare ripening on the vine and after picking. The first year two glasshouses with the cultivars "Delcro" and "Jupiter" of a commercial crop were used. From each cultivar two different trusses were chosen and from these one fruit per truss, always at the same position. No fruits were removed from the hundred plants taken per experiment. Picking was according to the grower's schedule. The chosen fruits were labelled and divided into two groups, one was left on the vine, the other was picked at turning (colour stage 2, according to Stenvers and Stork (18)) and kept in the glasshouse under the same conditions. Total time for development of the fully orange colour was determined.

These experiments were repeated but with additional treatments. The flowers were hand-pollinated on three dates, with four days intervals. When the first fruit was set the other fruits on the truss were removed, four to five fruits per plant being thus allowed to grow. Plants were topped after the fifth truss and axillary shoots removed. The fruits were picked on the day when the first fruit started to colour (stage 2). Each sample had its control sample, pollinated on the same day but growing on the vine until the fully orange stage. Two cultivars

"Extase" and "Moneymaker" were used, 100-150 plants per experiment. All fruits were analysed in the fully orange stage for the same properties as in the fruit:leaf ratio experiment.

The rate of ripening of tomatoes on the same truss was investigated in commercial greenhouse crops. The trusses chosen were the third and fourth truss from a crop of "Delcro" and the sixt truss from a crop of "Jupiter" tomatoes. The data of fruit set were not exactly known. The day when the fruits showed the first symtoms of colouring (stage 2) was noted as the first day of ripening on the vine. Fruits were picked when fully orange and weight, volume, rate of ripening and number of seeds were determined.

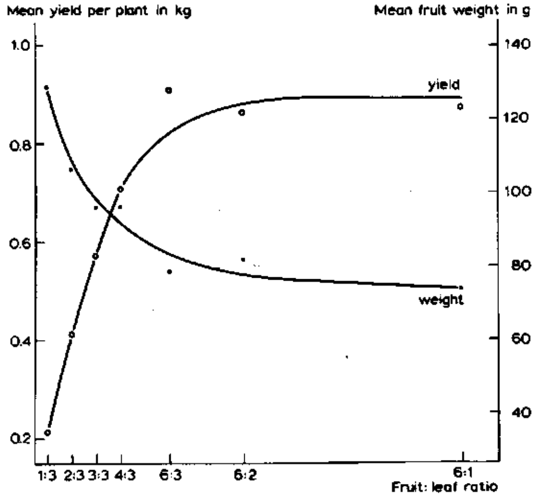
Results

a. Effect of the fruit:leaf ratio

Weight and volume of the individual fruits were used to determine fruit growth. Under practical growing conditions fruit growth is limited by competition;Fig. 1. Removal of fruits increases the size and weight of the remaining ones, but insufficiently in order to maintain the yield per plant, which decreases significantly below a fruit:leaf ratio of 6:3.

Fig. 1: Influence of fruit:leaf ratio on individual fruit weight and yield per plant

Einfluss des Frucht-Blatt Verhältnisses auf das individuelle Fruchtgewicht und die Ernte pro Pflanze



The rate of development is given by the time interval between pollination and picking dates. Analysis of variance showed no significant differences in the rate of development at the different fruit:leaf ratios. The internal ethylene concentration, softness, and ascorbic acid content showed no correlations with the different treatments.

In normally ripening tomatoes colouring of the locular tissue coincides with the colouring of the pericarp. When the calyx end of the fruit starts colouring the adjacent jelly colours too. It was observed, however, that this colouring not always occurs, the jelly becoming not coloured according to the outward state of ripeness but remaining yellowish red or greenish to dark-green. This "off-colour" can already be detected when the fruits start colouring at turning.

Figure 2: Mean percentages of fruits with green jelly of the first three trusses in the different treatments
Mittlere Prozentsätze der Früchte mit grüner Lokularmasse der drei ersten Trauben verschiedener Behandlungen

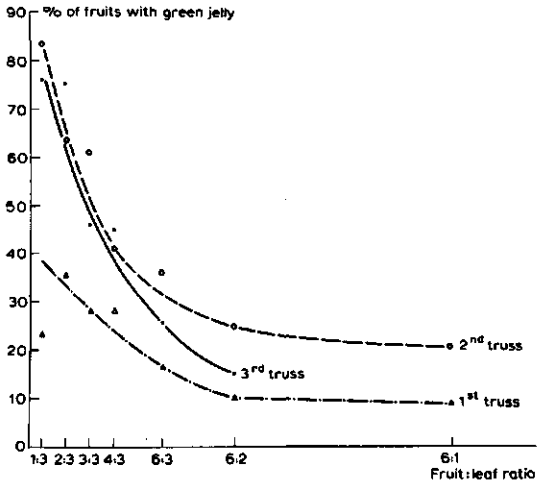


Figure 2 shows that greenish locular tissue becomes predominant at low fruit:leaf ratios. This effect is less developed in the first cluster, possibly because of its exclusive position as derived from the end bud of the main stem (2). The green colour points to a factor affecting the ripening of the jelly either by its accumulation or by its absence. The ascorbic acid content of fruits with green locular tissue was higher than in normally ripened fruits, as shown in Table 1.

Table 1. The ascorbic acid content in mg/100g fresh weight of "Moneymaker" fruits with green and red locular tissue at different stages of ripeness, as described by Stenvers & Stork (1975)
Ascorbinsäuregehalt in mg pro 100 g. Frischgewicht von "Moneymaker" Früchte mit grüner oder roter Lokularmasse verschiedener Farbklassen

Ascorbic acid content in mg per 100g fresh weight

Colour stage	Experiment 1		Experiment 2		Experiment 3	
	normal	green	normal	green	normal	green
2	-	-	-	-	17.0	24.2
3	17.0	25.8	12.2	22.4	15.4	22.5
4	22.0	24.2	14.6	24.3	18.1	20.3
5	18.7	20.9	13.8	19.3	18.7	22.3
6	-	-	15.7	19.6	19.2	22.5
7	-	-	16.0	25.4	-	-
Average	19.2	23.6	14.5	22.2	15.7	22.4

Most of the ascorbic acid, however, is located in the pericarp tissue (Stenvers & Stork, 1976).

Samples of seeds from fruits with red and fruits with green locular tissue were tested for germination.

Fig. 3: Germination at 20°C of seeds from green and red locular tissue
Keimfähigkeit bei 20° von Samen aus grüner und roter Lokularmasse

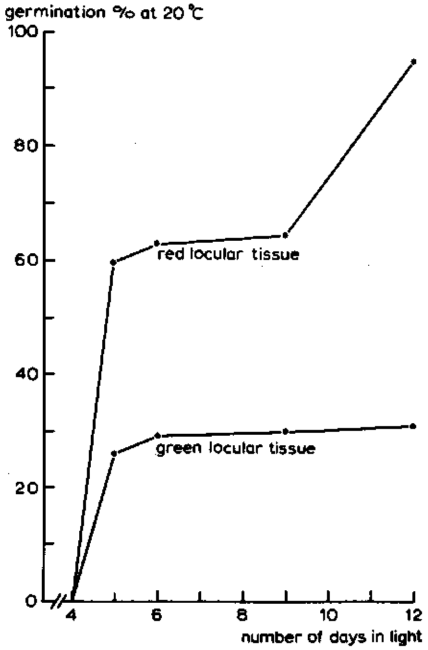


Figure 3 shows that seeds from ripe fruits with green locular tissue germinate much less in light than seeds from fruits with normally coloured tissue. Germination in darkness gave similar results as in light.

b. <u>Effect of picking on ripening</u>

Ripening on the vine was compared with ripening after picking at the turning (breaker) stage. Table 2 shows the mean weight at the fully orange state.

Table 2 Mean fruit weight in g of the different experiments
Mittleres Fruchtgewicht in g der verschiedenen Versuche

Treatment	Pollination data*	Mean weight in g			
		Cultivar			
		Extase		Moneymaker	
		Experiment		Experiment	
		1	2	1	2
On the vine	0 1)	146	147	96	123
	-4 2)	161	155	100	109
	-8 3)	152	131	120	115
picked and stored	0 1)	136	138	105	117
	-4 2)	126	125	87	97
	-8 3)	108	120	89	93
*Pollination data					
1) first date		25/8	7/9	4/9	16/9
2) second date		29/8	11/9	8/9	20/9
3) third date		2/9	15/9	12/9	24/9

The number of fruits per truss was restricted to 1. Both weight and volume per fruit were higher for fruits ripened on the vine, the difference being significant between the 80% and 95% level. Apparently the fruits continue growht during ripening on the vine.

Table 3 gives the rates of development of the fruits until fully orange of the different experiments of the last year.

Table 3. Rate of development of fruits either picked at the moment that the first fruit of pollination date 0 came into the breaker stage (colour stage 2) or remaining on the vine

Entwicklungsgeschwindigkeit bei Früchten die gepflückt wurden am Tage dass die erste Frucht des Bestäubungsdatum 0 die Farbklasse 2 zeigte oder die nicht gepflückt wurden

Pollination date	Days between pollination and fully orange coloured							
	1. "Extase"		2.		3."Moneymaker"		4.	
	vine	picked	vine	picked	vine	picked	vine	picked
0	55.6	55.5	54.5	55.3	51.8	53.0	-	-[1)]
-4	54.8	55.4	53.2	54.1	52.6	52.3	51.5	52.7
-8	55.4	54.4	54.4	54.2	50.2	48.7	50.6	49.4
0	69.0	67.0	75.0	74.5	62.5	62.5	70.0	71.0
-4	70.5	65.0	73.5	73.5	66.0	62.0	68.0	68.5
-8	70.0	68.0	71.0	70.5	64.5	60.5	70.0	68.0

1) because of a severe attack of Botrytis cinerea Pers. Pers. in one of the repetitions these data were abandoned

According to the signed rank test the rate of colour development on the vine is significantly ($p \geq 95\%$) slower than when the fruits are detached from the plant. Because, however, the differences are small, this might be an indication of a slight retarding effect of the plant on fruit ripening.

Internal ethylene concentration, softness, number of seeds, and ascorbic acid content gave no statistically significant differences between picked fruits and fruits left on the vine.

c. Effect of position on the truss

To determine the growth rate of tomatoes on the same truss three experiments in two glasshouses were set up with "Jupiter" and "Delcro" fruits.

Table 4 Average weight per fruit in stage 6 (fully orange) and the average number of days for ripening on the vine (colour stages 2 to 6)
Mittleres Gewicht per Frucht der Farbklasse 6 (voll orange) und mittlere Anzahl der Tage erforderlich zur Reifung an der Pflanze (Farbklasse 2 bis 6)

Position of fruit on the truss	Delcro				Jupiter	
	Truss 3		Truss 4		Truss 6	
	weight in g	mean number of days between colour stages 2 and 6	mean weight in g	mean number of days between colour stages 2 and 6	mean weight in g	mean number of days between colour stages 2 and 6
1	55	9.1	62	8.4	77	8.1
2	65	8.8	65	8.5	81	8.2
3	62	9.3	63	9.1	76	8.7
4	69	9.0	66	9.3	73	8.6
5	61	10.0	63	9.0	59	8.5
6	59	9.6	62	9.0	67	8.3
7	61	9.2	-	-	-	-
8	61	9.8	-	-	-	-
F	2.42	-	0.52	-	4.63	-
F theor. 95%	2.06	-	2.29	-	-	-
F theor. 99,9%					4.45	

The data of Table 4 show no consistent effect of the position of the fruit in the cluster on its size or rate of ripening. There is no correlation between rate of ripening and fruit weight either. Average volume and largest diameter show the same results.

Figure 4 gives the average weight of the fruits on the vine of the fruit:leaf ratio experiments, showing that the first fruits on a truss are not necessarily the largest ones.

Figure 4 Influence of the number of fruits and their position on a truss on the mean fruit weight
Der Einfluss der Anzahl der Früchte und deren Reihenfolge pro Traube auf das mittleren Fruchtgewicht

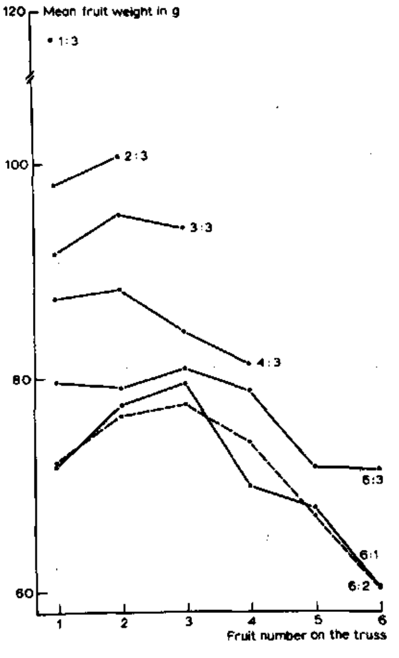


Table 5 The average time interval in days between the breaker stage of a given fruit and the fruit that arrived at that stage first.
Mittelwert des Zeitintervalles zwischen Anfang der Reifung (Farbklasse 2) einer Frucht und der Frucht die dieses Stadium zuerst erreicht hat.).

Position of fruit on the truss	cv. Delcro		cv. Jupiter
	Truss 3	Truss 4	Truss 6
1	1.0	0.8	0.8
2	2.1	1.4	2.5
3	2.6	5.1	4.1
4	3.5	6.1	6.2
5	6.4	10.2	9.0
6	9.0	13.9	10.5

In table 5 it is shown that the average time interval between reaching the breaker stage (stage 2) of the first fruit and the last fruit on a truss differs between 8 and 13 days.

It is generally assumed that the first fruit on a truss is always the first to mature, then the second fruit follows etc. From the first four fruits of the trusses used for these experiments, for each pair of successive fruits the percentages of the trusses were determined on which the preceding fruit was first, later or simultaneously at a certain colour stage of ripeness as the successive fruit. Because for all three trusses the same tendency was found, table 6 presents for convenience reasons the average figures of the three experiments.

Table 6 Average percentages of the number of times one of two successive fruits of the first four fruits on the truss was first, later or simultaneously at a certain colour stage of ripeness.
Mittlere Prozentsätze der Häufigkeit dass eine von zwei aufeinanderfolgenden Früchten der ersten vier Früchte einer Traube eher, später oder gleichzeitig eine gewisse Farbklasse der Reifung erlangte.

Fruit numbers	1 - 2			2 - 3			3 - 4		
Colourstage of ripeness	a*	b	c	a	b	c	a	b	c
2	57	27	16	62	23	15	69	26	5
3	57	28	15	61	25	14	71	20	9
4	49	30	21	62	22	16	67	24	9
5	51	25	24	60	20	20	68	18	14
6	51	21	28	65	15	20	56	15	29

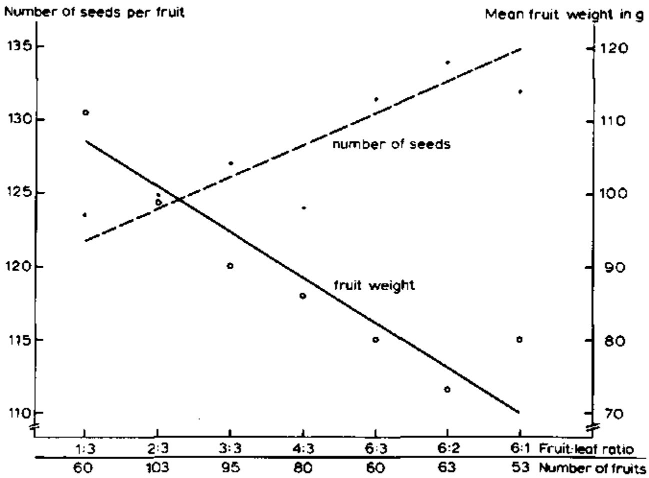
*a. = The lower fruit number has arrived in a certain colour stage first.
b. = The lower fruit number has arrived in a certain colour stage later.
c. = Both fruit numbers have arrived in a certain colour stage simultaneously.

It can be seen that a fruit often retains its original position. Generally, the number of "first" fruits of two successive places on the truss arriving first at a certain stage of ripeness can be put at about 50-60%.

d. Effect of seed number

According to the literature (7, 13, 20) the number of seeds influences the growth rate and the ultimate size of the fruit. That other factors may overrule this relationship is demonstrated in fig. 5, which shows that at an increasing fruit:leaf ratio the smaller fruits contain more seeds. Within each fruit:leaf ratio, however, fruit size and seed number were positively correlated.

Figure 5 Correlation between the mean number of seeds and the mean fruit weight at the different fruit:leaf ratios.
Korrelation zwischen der mittleren Samenzahl und des mittleren Gewichtes der Früchte der verschiedenen Frucht-Blatt Verhältnissen.



All correlations between seed number and days from pollination to ripeness are positive, six out of nine significantly at the 95% level. This means that in these experiments more seeds go with a longer growing period.

The fruit used for counting seeds were divided into stem and blossom halves. In these halves the seeds of the two locules were counted separately. It turned out that in 91.4% of the fruits the blossom half had more seeds than the stem half. Comparing the two locules showed no fruit with locules of equal size, one being always smaller and with less seeds than the other. This was valid for all cultivars involved. Looking for the cause of this asymmetry the ovary was examined before fertilization had taken place. After removal of the ovary wall, the ovules of each locule could be counted (photograph 1). In all of the 46 ovaries opened one locule was smaller than the other. In this smaller locule the number of ovules was less than in the other, differences varying from 8-55. Therefore, the difference in size of the two locules is a matter of initial flower development.

Photograph 1 The ovules of an unfertilized tomato flower (40 x)
Die Eizellen einer unbefruchteten Tomatenblume (40 x)

Photograph 2 shows on the left a fertilized and on the right an ovary of an unopened flower, both upper sides being the smaller ones.

Photograph 2 Ovaries of a fertilized (left) and an unfertilized tomato flower (40 x)
Fruchtknoten einer befruchteten (links) und einer unbefruchteten Tomatenblume (40 x)

Discussion

Normally fruit growth is limited by competition for nutrients from the foliage.

Reducing the fruit:leaf ratio gave heavier fruits, the developmental rate being neihter retarded nor accelerated.

At the lower fruit:leaf ratios the number of fruits with abnormally coloured locular tissue increased. Apart from the diverging colour no other differences as to taste or softness of the jelly could be observed. Neither early harvesting nor the number of seeds influenced the colouring of the locular tissue. However, the fruits with the unusually coloured jelly contained more ascorbic acid than fruits with normally coloured locular tissue. The germination of seeds from green locular tissue was markedly inhibited.

The evidence that fruits detached from the plant ripen faster than those left on the plants (4, 5, 10, 14) is derived from observations on avocado and apple. It indicates that the plant either supplies a ripening inhibitor, or withdraws a ripening stimulating factor. According to Sfakiotakis and Dilley (16) a substance originating in the leaves is translocated into the fruits preventing autocatalytic ethylene production. A low fruit:leaf ratio might promote the influx of such a ripening retarding substance into the fruits contributing, on the one hand, to the green off-colour of the locular tissue and, on the other hand, keeping the seeds dormant. This agrees with the suggestion of Frenkel and Dyck (9) that a substance from pear seeds prevents ripening even at higher levels of ethylene. Their research indicates that the factor might be an auxin but, according to Dostal and Leopold (8), the substance might be a gibberellin as well. In the fruits at low fruit:leaf ratios the seed abortion may be due to an increased supply of gibberellins from the foliage (20). Other hormonal substances may be involved in the fruit ripening as well (3). If, however, the foliage of tomato plants should supply the fruits with a substance inhibiting ripening, than ripening should be speeded up by picking the fruit at an early stage of ripening. In our experiments the ripening of freshly picked fruits has not been accelerated. The occurrence of a ripening-inhibiting substance from the foliage, shown for mango (4) and apple (16), is not conclusively demonstrated in tomato. However, the experiments were terminated when the fruits reached colour stage 6. It might be that at the later stages, when the intensity of the ripening metabolism is declining, an influence of the foliage on the ripening will be detectable.

There is no consistent difference in weight between the fruits on a truss (Table 5). The flower nearest to the main axis is the first to be fertilized in 50-60% of the trusses only; its fruit not always attains the greatest size and weight.

A good correlation between fruit size and number of seeds (7, 13, 19) was confirmed for each fruit:leaf ratio. However, contradictory to earlier findings, it was found that ripening is retarded at increasing seed numbers.

An interesting observation is that a decrease in fruit:leaf ratio enables a better fruit growth but also leads to a decreased number of seeds, resulting in an inverse relationship between fruit size and seed number. Again, gibberellins from the foliage may be involved in causing embryo abortion.

It was observed that one locule of a tomato fruit is always smaller than the other, also containing less seeds. Differences in number of seeds varied between 1 and 79. These differences equal the differences in number of ovules in the ovary locules and can, therefore, be ascribed to a difference in initial flower development.

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Summary

The optimum picking time for tomatoes is determined from physiological and anatomical data.

A special method of photographing changes in volume of tomatoes on the vine is described. A new technique of printing shows directly the change in volume at different stages of development.

Specific gravity increases in the course of ripening as a result of structural changes in the parenchymous cells of the pericarp tissue, involving a reduction in size of the intercellular space. The increase in specific gravity of fruits on the vine is accompanied by increases in volume and weight, whereas picked tomatoes decrease in size while ripening.

Fruits picked when 50% orange or even riper give the highest yield and best postharvest qualities.

No differences in postharvest quality were found between fruits picked early in the morning and in the afternoon.

Zusammenfassung

Der optimale Pflückzeitpunkt für Tomaten wurde aufgrund physiologischer und anatomischer Daten festgestellt.

Es wurde eine spezielle Methode beschrieben um auf photographischem Wege Veränderungen im Volumen einer Tomate an der Traube zu folgen. Eine neue Aufnahmetechnik legt die Veränderungen im Volumen bei den unterschiedlichen Reifestadien direkt fest.

Es wurde gezeigt dasz das spezifische Gewicht zunimmt während der Reifung und dasz diese Erscheinung auf einer strukturellen Veränderung in den parenchymatischen Zellen des Perikarps beruht, das eine Abnahme in der Grösze des Interzellularraumes zur Folge hat. Die spezifische Gewichtszunahme der Früchte an der Traube wird von einer schwächeren Volumen - und stärkeren Gewichtszunahme verursacht. Geplückte Tomaten weisen jedoch während der Reifung eine Gröszeabnahme auf.

Den höchsten Ertrag und die beste Qualität bei der Ernte erhält man im Stadium der 50% orange Reifephase oder sogar darüber hinaus.

Es wurden keine Unterschiede in der Qualität festgestellt zwischen Früchte die früh morgens und nachmittags geerntet wurden.

Introduction

One of the most important factors determining the postharvest quality of fruits is the right time of picking. This paper is meant to establish the best time of harvesting tomatoes, especially also in relation to keepability for export.

In the Netherlands most growers pick all coloured tomatoes, from turning to red, simultaneously, early in the morning. It depends on the number of pickings per week in which average stage of ripening the fruits are. Since we have shown earlier (13) that the fruit still increases in volume during ripening on the vine, we set out to see whether the yield of more ripened tomatoes is higher than that of less ripe ones. Attention was paid to the shift in the weight:volume ratio in ripening fruits, also with the help of anatomical studies.

The daily picking time is a matter of quality and economy. Using a picking team for a normal daytask is cheaper than for the very early morning hours only. This last procedure has been favourite up to now, because fruits picked later were thought to be less in quality. For several years experiments were carried out with tomatoes picked between 5.00 and 7.00 a.m. and between 2.30 and 5.00 p.m. when the greatest heat of the day had had its full influence on the plants. The quality of these fruits was compared.

Experimental

Experiments were done with various cultivars to account for varietal differences.

To show that tomatoes still increase in volume after the mature-green stage, a special photographic technique was employed: Figures 1 and 2.

Figure 1 Device for measuring volume increase of fruits on the vine
Gerät zur Messung der Zunahme des Volumens von Früchten an der Pflanze

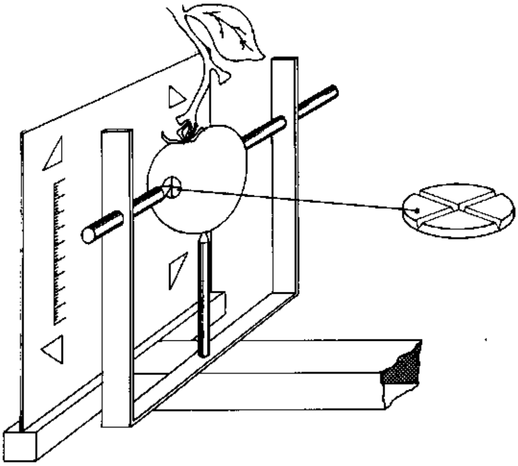
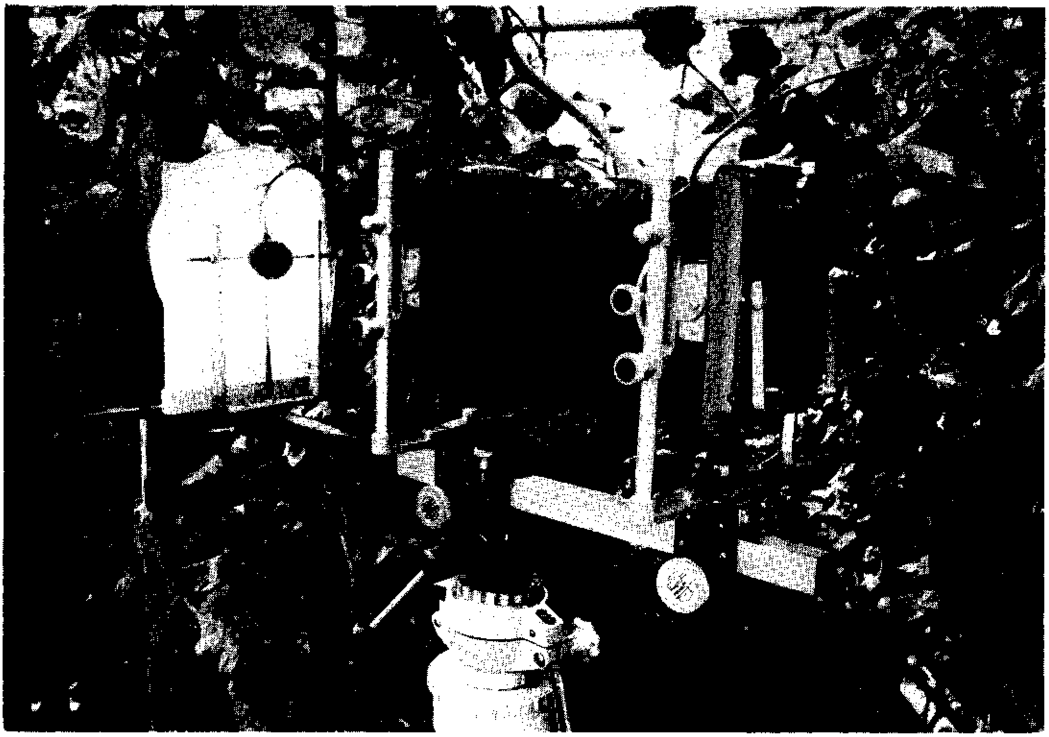
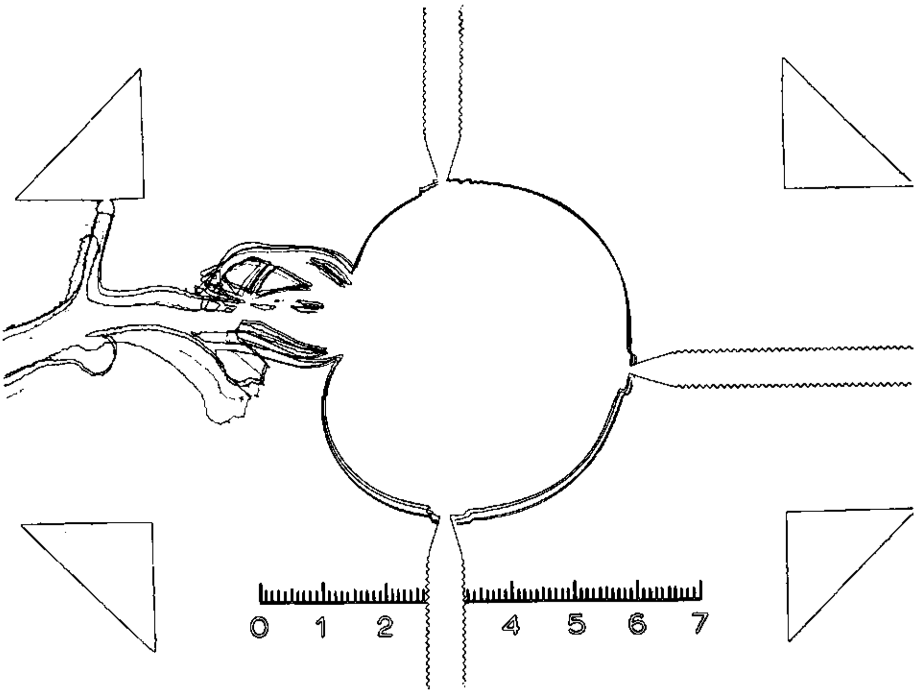


Figure 2 Measuring device mounted on the camera ready to make the photograph
Gerät zur Messung auf das Stativ der Kamera montiert



A mount was designed to photograph the growth of a fruit on the vine. On the ground glass behind the tomato, marks were placed which coincide with marks on the camera glass, thus avoiding later aberration from the original position. The fruit itself had also small marks that could be placed between the pins of the measuring device. Two of these were fastened, the third was flexible and could be adjusted to the growth of the fruit. During ripening several photographs were taken from the same fruit with a flash-light behind the tomato giving 1200 Watt/sec. The film used was high contrast graphic material type 081 p Agfa-Gevaert. The photographs were copied on Agfa-contur film, so that only the contouring of the fruit was visible. At the end these copies were put on top of one another, according to the fixed marks, and then printed together.
In this way the increase of volume was made visible and measurable: Figure 3.

Figure 3 Growth of a mature green tomato fruit till full ripe
Wachstum einer reifgrünen Tomate bis zur vollen Reife



Specific gravity was measured of freshly picked fruits and of fruits detached from the plant and stored at 19°C and a relative humidity of 88%. The weight in air was divided by the volume of these fruits, the latter being measured by displacement of water. Possible changes of the intercellular space can greatly influence the weight:volume ratio. Therefore, the course of structural changes was followed. Fruits were cut in halves, the locular tissue removed and the pericarp tissue fixed in liquid nitrogen. After freeze-drying samples were directly prepared for the electron microscope JEOL JSM-U3 at the Technical and Physical Engineering Research Service, Wageningen.

Ten experiments comparing different daily picking periods were carried out during subsequent years with commercial crops of "Maascross", "Delcro", "Yelvic", and "Moneymaker". The storage temperatures used were 19°C, and 1 to 5 days at 0°C followed by 19°C. The humidities were 72% and 87%. Softness was measured regularly during storage.

In order to investigate whether picking of tomatoes in a more advanced state of ripeness increases yield two experiments were conducted with cv. Moneymaker from two different glasshouses. Fruits were picked in two lots, e.g. from turning (colour stage 2 according to Stenvers and Stork, 1976) to 50% orange (colour stage 4) and from 66% orange (colour stage 5) to red coloured (colour stage 7). Picking dates were according to the practice of the respective growers. The fruits were weighed directly after picking. Experiment one had 25 dates of picking, starting on May 26 and ending on July 21. Experiment 2 started on July 8 and ended September 6, in total 18 picking dates.

Results

a. Specific gravity

Table 1 gives the mean specific gravity for "Delcro" fruits from the third truss, the second fruit picked at different colour stages of ripeness and stored at 19°C and a relative humidity of 72%. As was shown earlier (Stenvers and Stork, 1976), specific gravity increases during ripening, but the differences in specific gravity between stored and fresh fruits are not significant.

Table 1 Average mean specific gravity of "Delcro" fruits, third truss, second fruit
Mittleres spezifisches Gewicht von "Delcro" Früchten, 3. Traube, 2. Frucht

colour stages reached during storage at 19°C and rel. humidity 72%					
colour stage at picking	2	3	4	5	6
2	*0.991*	0.993	0.995	0.998	1.000
3		*0.994*	0.998	1.001	1.003
4			*0.995*	1.000	1.005
5				*0.998*	1.004
6					*0.999*

The standard deviation is between 0.001 and 0.002. The values for freshly picked fruits are in italics.

Also for fruits picked at random the differences in specific gravity between stored and fresh fruits are not significant: Table 2.

Table 2 Average specific gravity of "Delcro" fruits, picked at random
Mittleres spezifisches Gewicht von "Delcro" Früchten, Pflück mit Zufallsauswahl

colour stages reached during storage at 19°C and rel. humidity 72%					
colour stage at picking	2	3	4	5	6
2	*0.995*	0.999	1.001	1.002	1.006
3		*0.994*	1.001	1.002	1.005
4			*0.999*	1.000	1.003
5				*1.001*	1.006
6					*1.004*

The standard deviation is 0.001. The values for freshly picked fruits are in italics.

In order to determine losses in weight and volume during storage from both the selected and the at random samples, the percentages of the losses are calculated in percents of the original weight and volume. Table 3 shows that the volume decreases are larger than the weight losses, leading to increasing specific gravity. It can also be seen that when picked in a later stage the losses in weight and volume are less than when picked earlier.

Table 3 Average decrease in weight and volume of "Delcro" fruits, third truss, second fruit, or picked at random during storage at 19°C and a relative humidity of 72%
Mittlere abnahme in Gewicht und Volumen von "Delcro" Früchten, 3. Traube, 2. Frucht und Pflück mit Zufallsauswahl, während Lagerung bei 19°C und 72% relativer Feuchtigkeit

	colour stage at picking	colour stage reached during storage									
		weight in g					volume in ml				
		2	3	4	5	6	2	3	4	5	6
third truss second fruit	2	100	99.4	99.8	98.1	97.5	100	99.1	98.3	97.3	96.6
	3		100	99.0	98.0	97.5		100	98.6	97.4	96.6
	4			100	98.7	97.7			100	98.3	96.9
	5				100	98.5				100	97.9
picked at random	2	100	99.3	98.4	97.8	96.8	100	98.9	97.8	97.0	95.7
	3		100	98.1	97.5	96.6		100	97.5	96.7	95.6
	4			100	98.6	97.8			100	98.1	97.2
	5				100	98.2				100	97.7

On the vine specific gravity also increases (italics in tables 1 and 2), but since the fruit volume increases on the vine, the increase in specific gravity must in this case result from an even larger augmentation of the fruit weight.

The changes in tissue structure during ripening are demonstrated in Figures 4 and 5.

Figure 4 Anatomical changes of the parenchymous tissue of the pericarp of tomatoes (see text for explanation)
Anatomische Veränderungen des Parenchyms des Perikarpes der Tomate (Erklärung siehe im Text)

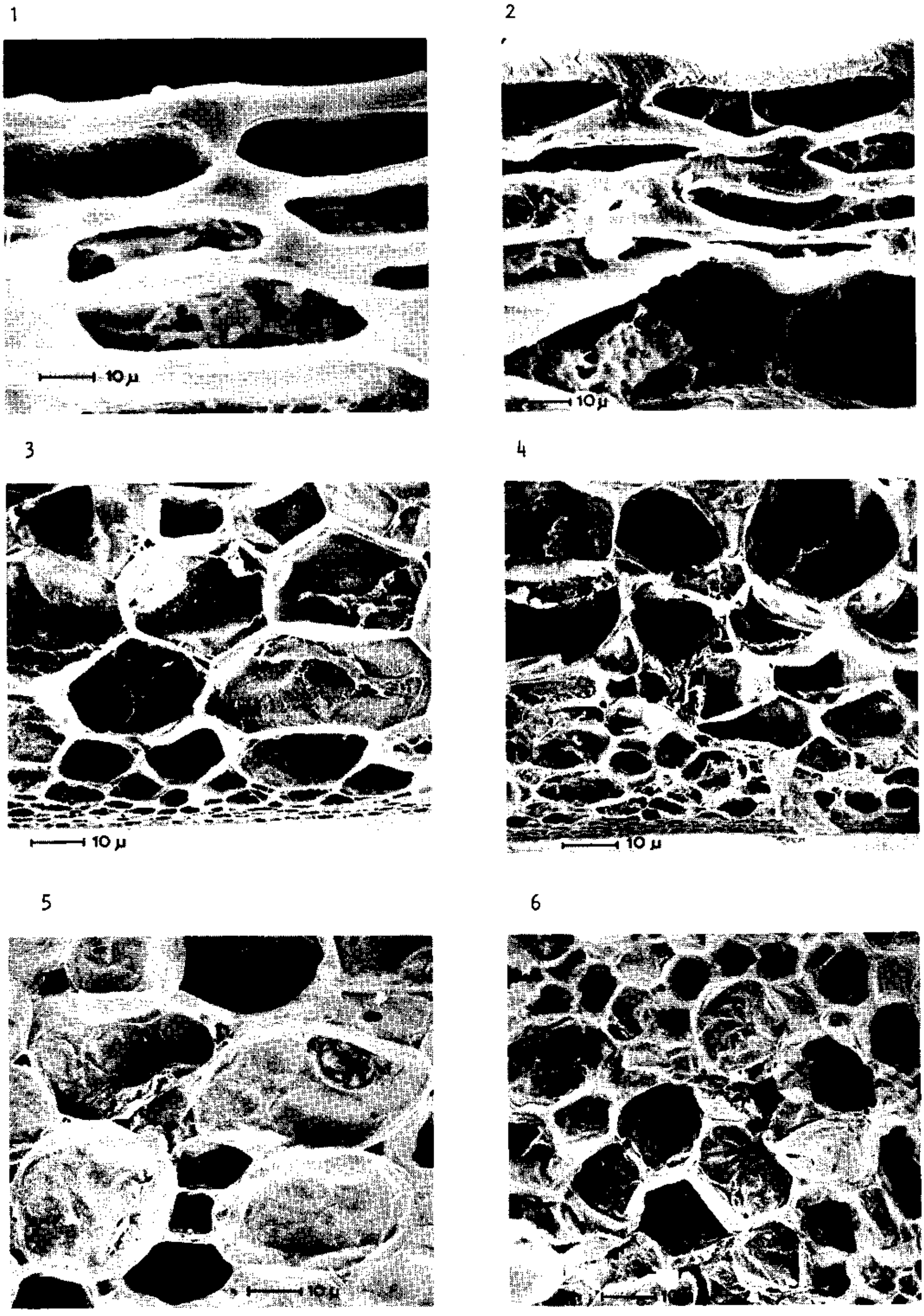
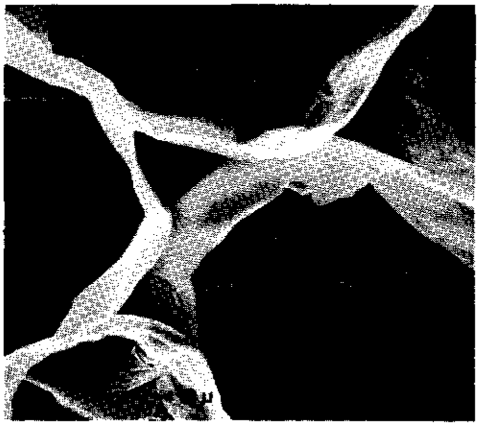


Figure 5 Anatomical changes of the intercellular spaces in the parenchymous tissue of the pericarp of tomatoes (see text for explanation)
Anatomische Veränderungen im Interzellularraumes im Parenchym des Perikarpes der Tomate (Erklärung siehe im Text

7



8

The photographs 1 and 2 are from the epidermis tissue directly under the cuticula, in the mature green and in the fully red colour stages, respectively, showing the desintegration of the cell walls during ripening. Photographs 3 and 4 are from freeze-dried, 5 and 6 from fresh material, 3 and 5 from mature green, 4 and 6 from fully red tomatoes. These cell layers are situated directly underneath the epidermis. The structure of the parenchymous cells is strong and rectangular in the mature green stage. This regularity has disappeared in the red ripe stage. Also the cell contents are at the verge of desintegration, as already observed by Mohr and Stein (11). The photographs 7 and 8 show intercellular spaces in the parenchymous tissue of the mature green and the fully red stage, respectively, demonstrating that the cell wall breakdown during ripening (10) results in smaller intercellular spaces. When ripening occurs during storage the same sequence of events can be observed, tissue weight and volume both decreasing, but volume more than weight. These anatomical findings explain the observed shifts of the weight:volume ratio.

b. Time of picking

In the subsequent years a total of 376 average softness determinations were made on samples of 25 fruits from pickings in the morning and in the afternoon, allowing for 188 comparisons. The fruits harvested in the afternoon were in 132 cases firmer and in 52 cases softer than those picked in the morning. In 4 cases the fruits were equally soft.

c. Stage of ripeness at picking

Since fruits continue growth during ripening on the vine, it was investigated whether the picking of fruits in more advanced stages of ripening leads to appreciable yield increases. For this purpose, fruits were harvested either in the usual way, between mature green and half orange ("green picking"), or between 66% orange and red ("red picking"). Results are presented in Table 4.

Table 4 Average yield data for the usual "green" picking and the advanced "red" picking of "Moneymaker" tomatoes
Mittlere Ernte daten des gebräuchlichen und eines fortgeschrittenen Erntezeitpunktes von "Moneymaker" Tomaten

	experiment I		experiment II	
	green picking	red picking	green picking	red picking
total yield(kg)	213	235	369	396
average yield per plant (kg)	3.14	3.31	3.89	4.17
in %	100	110.4	100	107.2
total number of fruits	3666	3715	4980	5078
average weight per fruit	58.1	63.3	74.2	78.0
in %	100	108.9	100	105.1

The average weight per fruit is 5 to 9% higher for the red pickings than for the green pickings. The average yield per plant is 7 to 10% higher for red picking than for green picking, as are the total yields.

Table 5 gives the data of the mean number of days for the different colour stages at picking (14) required to develop from stage 6 (fully orange) to stage 8 (red and soft).

Table 5 Average number of days for different colour stages at picking required to develop from colour stage 6 (fully orange) to 8 (red, ripe) during storage at 19°C and a relative humidity of 88%
Mittlere Anzahl Tage der verschiedenen Farbklassen während der Ernte benötigt zur Reifung von Farbklasse 6 (voll orange) bis 8 (rot, reif) während der Aufbewahrung bei 19°C und einer relativen Feuchtigkeit von 88%

colour stage at picking	"Moneymaker" 1965	"Moneymaker" 1966	Craig 1966
1	-	10.4	4.6
2	4.1	10.3	6.8
3	4.0	11.2	8.9
4	6.1	11.7	10.0
5	6.2	12.7	10.6
6	6.2	16.2	14.2

The time to ripen from the fully orange stage increases when the fruits are picked at a later stage of ripeness. The Friedman test shows that the differences between the colour stages are significant at the 95% level. Thus the shelf life is longer when the fruits are picked in more advanced stages of ripeness. Moreover, these riper fruits turned out to be less susceptible to such adverse conditions as infection by Botrytis cinerea and low temperature.

Table 6 gives the result of the 11 storage experiments of 1968. In these experiments 14 different treatments at 0, 12 and

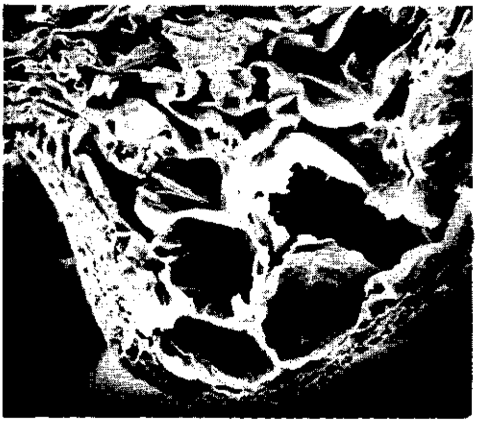
19°C were involved. The data of table 6 are the total percentages per colour stage picked which gained a shelf life, e.g. which after treatment remained completely sound and edible for at least three days when kept at 19°C and a relative humidity of 88%. The losses were mainly due to infection by Botrytis cinerea.

Table 6 Total percentage per colour stage of all 168 treatments that gained a shelf life in the 1968 storage experiments
Totaler Prozentsatz aller 168 Behandlungen pro Farbklasse der 1968 Aufbewahrungsexperimente die ein "Shelf Life" erreichten

colour stage	total % treatments with a shelf life
2	9
3	28
4	44
5	66
6	71

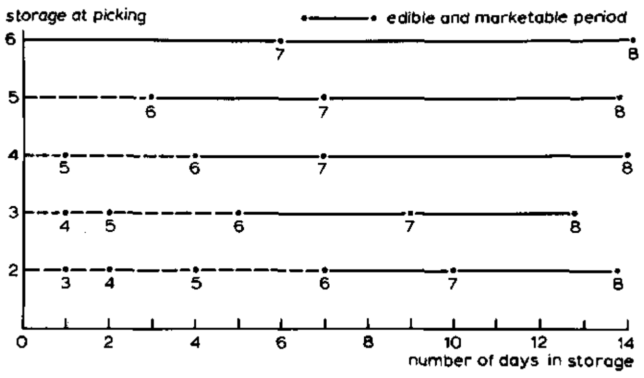
The table shows that the fruits picked at earlier stages are far more susceptible to different treatments than those picked at the more ripened stages. The structural changes in the epidermal cell layers and parenchyma of the pericarp by low temperature breakdown are illustrated in Figure 6, showing collapse of the tissue.

Figure 6 The effect of low temperature on cell structure (1000 x)
Das Effect niedriger Temperatur auf die Struktur der Zellen



Another interesting feature is that the total time of ripening in storage, i.e. from picking to fully red and soft, is approximately the same for all picking stages. With "Craigress" tomatoes, for instance, the ripening during storage was followed daily and the ripening was scored: Figure 7.

Figure 7 Average number of days between picking of the different colour stages and their ripening to stage 8 during storage at 19°C and a relative humidity of 88%
Mittlere Anzahl Tage zwischen Ernte und deren nachfolgenden Stadiën bis zum Stadium 8 der verschiedenen Farbklassen während der Lagerung bei 19°C und einer relativen Feuchtigkeit von 88%



It is obvious that the edible marketable period for the riper picking stages is longer than for the earlier picked fruits. For instance, for fruits picked in stage 2, it takes 13.7 days to reach stage 8, so the edible time between stage 6 and 8 being only 7 days, whereas it is 11 days for the picking stage 5, which only has to pass this stage to become edible. This holds for cv. Moneymaker and Delcro as well.

Discussion

By using a special photographic technique the increase in volume of fruits on the vine was established. But since the weight:volume ratio augments too, it is obvious that weight must increase even faster than the volume. With picked fruits the specific gravity also increases, but in this case by a larger decrease in volume than in weight.

The concomitant development of softness points to an anatomical cause for the increase in specific gravity. Scanning electron microscope studies reveal that the structure of the cell layers of the pericarp changes during ripening. Especially the cell walls become thinner because of solubilization of pectic substances. According to Hobson (5), softness is not significantly correlated with cellulase activities which are highest at the beginning and towards the end of the growth of the tomato fruit. The activity of cellulase rises with advancing ripeness, but the action of this enzyme does not appear to be a primary cause for the loss of firmness during ripening (7). Knegt et al. (10) demonstrated an increase in water-soluble pectins fron 7 to 35 percent of the total amount of pectins in ripening tomatoes, the increase resulting both from cell wall solubilization and from new synthesis. This is in accordance with other studies on tomatoes (3,4), pears (8), peaches (15), and apples (1,9).

It can be concluded that it is the pectic enzymes which degrade the walls and loosen the cohesion between cells, in this way decreasing tissue firmness during ripening. According to Bedford and Hobson (2), the first enzymatic mechanism contributing to the softening of the tomato fruit is still unknown. In the later green-orange stage hydrolytic polygalacturonase (5) and pectin esterase (6) are involved in this process. As a consequence the cells in the pericarp are pressed together, thus reducing the intercellular space. This causes the increase in weight: volume ratio, that is in specific gravity in the course of ripening.

The postharvest quality of tomatoes picked early in the morning and in the afternoon, and stored under various conditions of temperature and humidity, turned out to be practically the same. A tendency was found that the afternoon fruits were even firmer than those picked early in the morning, probably due to an adequate water supply to the plants. Thus the fruits will not suffer from loss of water but, on the contrary, will go on growing without interruption. Under these conditions tomatoes can be picked throughout the day without loss of quality.

On the vine the fruits continue to absorb water and solutes, whereas postharvest the increase in specific gravity is accompanied by weight loss. Therefore, picking in more advanced ripening stages results in a higher yield. Moreover, the keepability of later harvested fruits turns out to be improved, particularly the resistance against Botrytis rot and low temperature breakdown being increased.

A peculiar finding is that the total time between picking in the stages 2 to 6 and the ripening to stage 8 (14) was almost identical at all stages. This means that the edible and marketable period was considerably longer when the ripening of the fruits at picking was already more advanced. Earlier findings (13) gave no indication of such an influence of the plant on the rate of ripening of tomatoes, because in those experiments the fruits were picked at the mature green stage only and followed until they reached the fully orange stage 6. There might be a substance fed into the fruit whose influence on the rate of ripening is not recognizable until the metabolism of the fruit diminishes its activity, that is after the tomato has passed stage 6.

It can be concluded that picking tomatoes in a more advanced stage of colouring improves both the yield and the postharvest quality of the commodity. The harvest period need not be confined to the early morning hours.

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Summary

During subsequent years experiments were carried out with various storage conditions of tomatoes, varying in temperature, humidity and controlled atmosphere (C.A.) treatment.

The tomatoes were picked at different colour stages. Fruits harvested at green stages are more susceptible to damage at high humidity and low temperature than the more advanced ones, resulting in a shorter shelf life and more decayed fruits.

C.A. storage was, under the experimental conditions, no improvement of the standard storage at 12.5 - 13°C in air. However, there are indications that treatment with a fungicide and storage under reduced atmospheric pressure prolong storage life.

Zusammenfassung

Während mehreren Jahren wurden Versuche mit Tomaten unter verschiedenen Lagerungsbedingungen, bei verschiedener Temperatur, Feuchtigkeit und Kontrollierter Atmosphäre (C.A.) ausgeführt.

Die Tomaten wurden in verschiedenen Farbklassen gepflückt. Grün gepflückte Früchte sind mehr anfällig vor hoher Feuchtigkeit und niedriger Temperatur als die mehr gefärbten Stadien und haben deswegen eine kürzere Nachlagerung und mehr Fäulnis.

C.A.-Lagerung war, unter den Versuchsbedingungen nicht besser als die Lagerung bei 12.5 - 13°C normaler Luft. Es wird aber darauf hingewiesen dass eine Behandlung mit einem Fungizid und die Lagerung unter reduziertem Druck die Lagerung verlängert.

Introduction

Modern equipment of climate regulation in the glasshouses and new cultivars enable to obtain a good and valuable crop of tomatoes. Picking and post harvest handling, however, did not receive the attention required to preserve the quality of the fruits. Two factors markedly influence the post harvest quality of tomatoes.

The first factor is the stage of ripeness of the fruits at picking, which in practice varies from mature-green to fully red. Green tomatoes are thought to last longer, thus reducing the risks of overripeness during export. It will be shown that, on the contrary, green fruits increase the risks of decay and other deficiencies, without any advantage over the more red stages of ripeness regarding overripeness.

In the second place the conditions during handling and storage affect the shelf life of the commodity. Sometimes cold rooms are used to cool the tomatoes during a weekend or even longer at temperatures between 1 and 10°C. In this paper it is shown that temperature and other storage conditions play a considerable role in preserving the quality of the fruits.

Since it is reported in literature (6,7,8,10, 26) that a high relative humidity favours ripening of tomatoes, the question arose whether a lower level could lengthen the storage life, especially for the green-picked fruits. Low temperature tends to extend the life of fruits too, temperatures ranges from 12°C to 24°C being reported optimum for storage and transit of tomatoes (2, 3, 4, 9, 12, 13, 16, 17, 24, 25). However, these figures generally apply to crops grown in the open. Since the Dutch tomatoes are grown in glasshouses only, it was necessary to verify these findings from other countries.

C.A. storage of tomatoes is a difficult problem, possibly also influenced by the growing conditions in the different countries. In literature, storage conditions vary from 0% CO_2 and 3% O_2 (1, 14, 18, 23) to 5% CO_2 and 1% O_2 (6, 7, 18). The storage periods vary from 2 - 3 (23) to 12 weeks (6), the temperature is mostly above 12,5°C; only Lockhart <u>et al.</u> (11) and Tomkins (23) used 11° and 12°C, respectively. During two years experiments were carried out to find suitable atmospheres for Dutch tomatoes.

The quality of the tomato throughout the year is not uniform but depends on light, temperature and humidity during the growing season, the first and last crops usually having the poorest quality.

They are most susceptible to off-colours, softening and diseases like <u>Botrytis cinerea</u> Pers. Pers. Therefore, whenever possible the experiments were spread over the whole growing period.

Experimental

The experiments were carried out from 1965 to 1972. Several non-green back, half-green and green cultivars were included, usually picked at different colour stages (22, Stenvers and Stork 1975). The fruits used were carefully picked and not taken from the growers lot. Storage at different temperatures, humidities and atmospheres was carried out as follows.

The fruits were placed separately on trays in tents of 0.3 mm thick polyethylene, built in cold rooms which were held at a constant temperature. In the tents humidifiers were used in combination with small ventilators. The fluctuations in temperature within the tents were not more than 0.2°C, the relative humidity, once established, fluctuated within 1%. As three relative humidities: 88, 80, and 72%, were always compared at the same temperature, three lots of fruits were put into the same cold room.

In the first years the experiments were carried out with a relative humidity of 88%. In 1970-1971 various temperatures and relative humidities were used. In 1970 the following temperature treatments at 72,80 and 88% relative humidity were involved:

2 days at 11.5 - 12.0°C, followed by 19°C,
11 " " " " , " " " ,
2 " " 12.5 - 13.0°C, " " " ,
11 " " " " , " " " , and
19°C continuously

Rot and softness were measured at the end of the experiment after 17 days.

In 1971 the procedure was somewhat changed, the treatments at 72,80 and 88% relative humidity being as follows:

11.5 - 12.0°C, followed by 19°C,
12.5 - 13.0°C, id. ,
15°C id. , and
19°C continuously

After 3, 6 and 9 days at a lower temperature, samples were taken out and placed at 19°C. From these the loss of weight after a shelf life of at least 3 days at 19°C and the total shelf life were determined.

The C.A. experiments were carried out by placing 6kg fruit in boxes in zinc containers, placed in a cold room, enabling for various combinations of temperature, atmospheric conditions, and humidities. The containers were closed by a bicycle wheel with a special tyre. By inflating the tyre the container was closed airtight. Each container had an in- and outlet for scrubbing the air in a closed system. The relative humidity in a closed container with fruits was about 95%. Silica gel was used to lower the relative humidity to 66-70%. The atmosphere in the container was established as follows. Pure nitrogen was slowly pumped in to replace oxygen to the desired low level. By injecting CO_2 the required level of carbon dioxide was established. Excess of CO_2 was removed either completely by putting a bag with calcium oxide into the container, or to the desired level by scrubbing the air in a closed circuit through a saturated solution of potassium hydroxide. The oxygen level was maintained by ventilation.

During the experimental periods temperature, relative humidity, carbon dioxide and oxygen content, and the incidence of decay was measured daily, except for the C.A. storage experiments where colour and decay were determined at fixed intervals only. CO_2 was measured with the Bacharach Fyrite CO_2 apparatus model C.N.D., O_2 measurements were done with the Portable Oxygen Analyser Type OA 150 of Servomex Controls Ltd, England. Relative humidity was determined with the Assmann Psychrometer nr. 761.

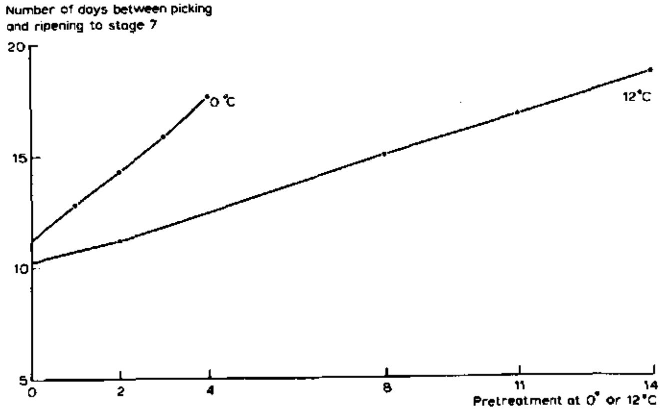
Shelf life, as a criterion for the usefulness of a treatment, was defined as the number of days in which all fruits remained edible when placed at 19°C at the fully orange stage. Minimum shelf life was three days. Treatments which did not satisfy this condition were discarded.

The quality of the tomatoes was determined for softness, colour, and the incidence if rot. Softness was measured with the softness meter described by Stenvers et al.(19). The colour was determined according to the scheme of colour stages described by Stenvers and Stork (22)

Results

Experiments from 1965 to 1970 invariably showed that the effect of storage at 0° on the rate of ripening and on the incidence of rot was much larger than that of 12°C. Figure 1 being an example for ripening.

Figure 1 The influence of storage temperature on the rate of ripening at 19°C of cv. Moneymaker fruits picked at colour stage 5 and ripened to stage 7 after storage at 0°C and 12°C (1968)
Der Einfluss der Lagerungstemperatur von 19°C auf die Reifung von Moneymaker Früchten gepflückt in Farbklasse 5 und gereift bei 19°C bis Farbklasse 7 nach Lagerung in 0°C und 12°C (1968)



At the lower storage temperature the deleterious effect on the fruits is larger and the deterioration becomes visible sooner, the time of ripening to stage 7 is somewhat retarded. Table 1 summarizes the results in 1968 as the ranking order of the total number of treatments with a shelf life. The lowest figures indicate the best treatments.

Table 1 Ranking order of the total number of treatments of the 1968 experiments which ended with a shelf life
Fruits were picked at different stages, stored first at 0°C, next at 12°C, and then ripened at 19°C
Die Reihenfolge der totalen Anzahl Behandlungen der 1968 Versuche die endeten met den bestimmten Shelf Life der gebrauchten Farbklassen
Früchte, gepflückt in verschiedenen Farbklassen sind gelagert zuerst in 0°C dann in 12°C und zuletzt gereift in 19°C

number of days at 12°C \ number of days at 0°C	0	1	2	3	4
0	1½	3½	6½	5	6½
2	1½	3½	8½	11	13
8	8½	10			
11	12				
14	14				

Treatments with the same number have the same ranking. Storage at 12°C for 2 days has no deleterious effect. The number of days at a lower temperature decreases the number of treatments with a shelf life, a negative correlation existing between the storage period at 0 and 12°C and the treatments with good results.

Table 2 presents the average shelf life obtained in 1965, 1966 and 1968.

Table 2 Average shelf life of 25 fruits per treatment picked at different colour stages in 1965, 1966 and 1968
Storage at 19^{o}C and 88% relative humidity
M = cv. Moneymaker
C = cv. Craigress
Mittlerer shelf life von 25 Früchten pro Behandlung verschiedener Farbklassen in 1965, 1966 und 1968
Lagerung bei 19^{o}C und einer relativen Feuchtigkeit von 88%
M = Moneymaker
C = Craigress

colour stage at picking	1965 M	1966 M	1966 C	1968 several cultivars
1	4.7	10.5	5.8	0
2	5.9*	10.0	7.4*	0
3	7.2*	10.6	9.5*	3.9
4	7.9	12.3*	9.9	10.6*
5	6.3*	11.9	9.2	13.5*
6	8.7*	16.2*	12.5*	17.6*

Significant differences P≤5% between 2 subsequent colour stages.

The experiments in 1965 and 1966 show, with mostly over 99% significance, that shelf life increases when the fruits were picked at a riper stage. This was confirmed in 1968 for several cultivars in 11 experiments throughout the growing season. Shelf life varies irregularly from year to year. Table 2 applies to the samples which obtained a shelf life at all.

Table 3 presents the number of samples of the 1968 experiments which ended with a shelf life, showing that the riper the fruits are picked, the higher the probability of obtaining a shelf life.

Table 3 Number of treatments per colour stage of the 1968 experiments which ended with a shelf life
Anzahl der Behandlungen pro Farbklasse der 1968 Versuche mit einem Shelf Life

colour stage at picking	spring		summer		autumn	
	number	percentage	number	percentage	number	percentage
2	14	25	0	0	0	0
3	38	66	4	7	1	2
4	46	84	14	27	7	17
5	53	95	31	55	16	38
6	-	-	-	-	37	88

Mathematical treatment of all experiments from 1965 to 1970 with the Friedman test gave a ranking order 6-5-4-3-2 for the colour stages at picking with a significance of 95%.

Analysis of variance of the softness measurements in 1970 showed no significant differences between the humidity regimes at 72, 80 and 88%. The differences between the temperature levels were significant at $P \leq 0.01$, except between 19°C and 2 days at 12.5°- 13°C, and between 11 days at 11.5° - 12°C and 12.5° - 13°C. However, the incidence of rot differed markedly: Table 4.

Table 4 Total percentage of rot in fruits picked at different colour stages and stored at different relative humidities, in 1970
Totaler prozentsatz fauler Früchte gepflückt in verschiedenen Farbklassen und gelagert in verschiedener relativen Luftfeuchtigkeit in 1970

colour stage at picking	relative humidity in %		
	72	80	88
2	2.5	7.5	62.5
3	17.5	22.5	75.0
4	5.0	20.0	22.5
5	7.5	7.5	15.0
6	12.5	17.5	15.0

The ranking test of Friedman showed significant differences between the three humidity levels at $P \leq 0.05$. Especially with the earlier picked fruits a high humidity may cause severe losses.

However a high relative humidity increases the liability to rot without influencing shelf life.

Table 5 shows fruits picked in stages 2 and 3 to be inferior to later picked ones, both for average shelf life and for the occurrence of rot.

Table 5 Number of treatments which led to a shelf life of three days at 19°C, and the average shelf life of the fruits picked at different colour stages in the 1971 experiments
Anzahl der Behandlungen der verschiedenen Farbklassen die einen Shelf Life von drei Tagen bei 19°C in den 1971 Versuchen aufwiesen und dessen mittleren Shelf Life

colour stage at picking \ % R.H.	number reaching a shelf life				average duration of shelf life			
	72	80	88	in %	72	80	88	average
2	4	5	4	42	3.7	3.7	3.6	3.7
3	10	9	5	77	4.6	4.3	4.5	4.5
4	10	10	10	100	6.3	6.7	6.2	6.4
5	10	10	10	100	6.6	7.4	7.5	7.2

Table 6 gives the average percentages of fruits ripened to stage 7 after storage at different temperature-relative humidity regimes.

Table 6 Average percentages of fruits, picked at the stages 2-6 and ripened to stage 7 at 19°C, after storage at different temperature and relative humidity regimes
Mittlere prozentsätze von Früchten, gepflückt in den Stadien 2 bis 6, gereift bis Stadium 7 bei 19°C, nach Lagerung unter verschiedenen Bedingungen von Temperatur und relativer Feuchtigkeit

relative humidity in %	storage temperatures before ripening at 19°C		
	11.5-12°C	12.5-13°C	19°C
72	62.5	66.5	82
80	63	70.5	77
88	67	71	73

The table shows that the relative humidity had no effect but storage above 12.5°C is safer than below 12.0°C. Since all the experiments show the same trend, for convenience Table 7 presents the total averages of the experiments, regardless of the storage time at the lower temperatures.

Table 7 Average percentages rot after 14 days C.A. storage at 12°C (1970)
Mittlere Prozentsätze der Faülnis nach 14 Tagen C.A. Lagerung bei 12°C (1970)

atmosphere		stages at picking		
% CO_2	% O_2	3	4	5
0	21	75	76	15
0	10	60	60	17
0	5	62	49	50
0	3	54	60	41
0	0	67	85	87
2	2	37	47	65
2	5	62	49	38
3	3	48	46	21
3	5	48	48	20
5	2	32	46	29
5	3	42	43	32
5	5	42	53	26
average:		52	55	37

Table 7 indicates that the fruits picked at a more ripened stage tend to tolerate C.A. conditions better, but that these conditions were highly deleterious. This overrules the positive effects on developments and colour.

In 1972, a C.A.-experiment was carried out at the humidity levels of 66% and 88%. After three weeks the C.A. storage was terminated. The fruits at the higher humidity were all decayed because of a severe attack of Botrytis. Comparing the weight losses per C.A. treatment and per colour stage for the lower relative humidity gave only a few significant differences between the stages 2 and 3. As tomatoes generally do not have heavy weight losses it is not remarkable that at the different C.A. regimes the various stages showed no significant differences.

Table 8 gives the results of the softness measurement per C.A. treatment and per colour stage of the 1972 experiment.

Table 8 Comparison of the averages of softness by the t-test of the different colour stages per C.A. treatment of the 1972 experiment
Vergleichung der Mittelwerte der Härte mittels des T-Tests der verschiedenen Farbklassen pro C.A. Lagerungsbehandlung des 1972 Versuches

C.A. storage		colour stage at picking	average softness in mm Load 300 g, time 5 sec., free fall 0.1 mm		
% CO_2	% O_2		$\bar{x}$ [1]	$S\bar{x}$ [2]	colour stage
0	5	2	2.16	0.07	5
		3	2.15	0.07	6
		4	2.16	0.05	6
		5	2.14	0.06	7
		6	2.41	0.07	7
0	10	2	2.24	0.05	6
		3	2.34	0.05	6/7
		4	2.25	0.06	6/7
		5	2.34	0.06	7
		6	2.35	0.07	7
0	21	2	2.10	0.06	6
		3	2.04	0.05	6
		4	2.16	0.05	6
		5	2.09	0.05	6/7
		6	2.19	0.08	6/7
3	5	2	2.37	0.06	4
		3	2.21	0.05	5
		4	1.74	0.04	6
		5	1.98	0.04	6
		6	1.95	0.04	6/7
5	10	2	2.14	0.05	5
		3	1.89	0.04	6
		4	1.76	0.05	6
		5	1.88	0.03	6
		6	1.90	0.05	6

1) average of 25 fruits
2) standard deviation of the average, in mm

It is obvious that during ripening in storage the colour stages 2 and 3 (green stages) soften more rapidly than the more coloured ones, reaching the softness of ripe fruits at an earlier stage already. In the atmosphere with 3% CO_2 and 5% O_2 , for instance, the final stages are respectively 4, 5, 6, 6 and 6 to 7. The stages 4 and 5 are significantly softer already than the stages 6 and 6 to 7. This is in accordance with the findings of the 1970 experiments.

A higher CO_2 percentage results in firmer fruits, especially when the colouring was more advanced at the start of the storage. Under our conditions the best storage seemed to be in an atmosphere of 3 - 5% CO_2 and more than 5% O_2 with a relative humidity of about 70%. An improvement might be a treatment with a fungicide against Botrytis, for example, treatment by dipping in a 100ppm pimaricin solution.

Discussion

Storage temperature is one of the main factors controlling the post harvest quality of fruits. As can be seen in Figure 1 the influence of 0^oC is more pronounced than that of 12^oC. The longer storage at or below 12^oC the longer it takes to ripen at 19^oC, and the greater the incidence of decay.

Humidity of the air is another important factor during storage. A relative humidity of 88% is too high and causes too much delay.

Generally, the later the fruits are picked the better they tolerate storage conditions. Both the reaching and the duration of the shelf life increase when fruits are picked at later stages of ripening (Tables 4 and 5). Moreover, these differences in shelf life do not involve a different total ripening period, which was remarkably constant for fruits picked at different stages of ripeness (Stenvers and Staden (21)). It can be concluded that the picking of fruits at more advanced stages of ripening than usual in common practice has considerable advantages for the post harvest quality of the commodity.

Although storage of tomatoes at 12.5 - 13°C gave good results over a period of 2 weeks already, C.A. storage was thought to extend this period. At the end of the C.A. experiments the green-picked fruits were as soft or even softer than the riper harvested ones, although their ripeness was less advanced (Table 8). However, the occurrence of Botrytis cinerea Pers. Pers. and the incidence of low temperature breakdown limits the possibility of C.A. to extend storage life (15). In preliminary experiments tomatoes treated with a fungicide such as pimaricin remained longer free from fungus attack, so possibly treated fruits might benefit from C.A. storage.

In small-scale experiments mature green tomatoes were stored in desiccators at reduced atmospheric pressures, e.g. 15 cm Hg (20). Under these conditions of low pressure storage (LPS), ripening could be considerably delayed because of retardation of both the onset and the rate of the ripening process. This turned out to be determined by the reduction in partial oxygen pressure rather than by the removal of evolved ethylene.

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Samenvatting der publikaties

De rijpheid van tomaten kan op verschillende wijzen worden gekarakteriseerd. De parameters, welke ten aanzien van de rijping het meest worden gehanteerd, zijn de zachtheid en de kleur van de vruchten. De manifestátie van beide verschijnselen kent een parallel verloop in geval van normale rijping.

In hoofdstuk I wordt voornamelijk op het verschijnsel van zachter worden ingegaan. In de Inleiding wordt een uiteenzetting gegeven over de tot dusverre bestaande meetappatuur, welke in het buitenland gebruikt worden, en de nadelen aan het gebruik ervan verbonden. De meters zijn nl. doorgaans destructief en kunnen daardoor slechts momentane informatie verstrekken, voorts in zeker opzicht ook subjectief omdat van de gebruiker een deskundige vaardigheid geëist wordt.

Voor de studie van het verloop van de zachtheid gedurende de rijping werd het wenselijk geacht de beschikking te hebben over een non-destructief instrument, teneinde dezelfde tomaten meermalen te kunnen meten. Bovendien ging de voorkeur uit naar een apparaat dat zich automatisch laat bedienen en de metingen met een zekere snelheid en accuratesse uitvoert.

Het door ons ontwikkelde instrument, dat tegemoet komt aan deze wensen, is in het eerste artikel uitvoerig beschreven, alsmede de metingen welke werden verricht ter toetsing van het apparaat.

Voor het doel van onze proeven werd de zachtheid van de vruchten gedefiniëerd als de mate van het, op mechanische wijze, indrukken van de schil zonder deze te beschadigen. De deformatie wordt gemeten in eenheden van 0,01 mm. Uit de proeven bleek dat de beste resultaten werden verkregen indien de metingen werden uitgevoerd met een bolronde plunjer, welke met een gewicht van 300 gram gedurende 5 seconden op het kelkeinde van de tomaat wordt gedrukt. De meter kan worden aangepast aan andere materialen dan de tomaat door het gewicht en de tijdsduur van de meting te veranderen.

Ondanks het nemen van, qua uiterlijk, homogene monsters tonen de zachtheidsmetingen een enkele maal een grote spreiding. Dit moet worden toegeschreven aan de eigenschappen van de individuele tomaat, welke grote verschillen kunnen vertonen, en niet aan uitwendige factoren als temperatuur en luchtvochtigheid.

De rijping van de tomaat is een continu proces, tijdens welk de kleur verandert van groen naar rood. Om het rijpingsproces aan de hand van de kleurveranderingen der vruchten te kunnen volgen is een indeling in een aantal, goed gedefinieerde kleurfasen noodzakelijk. In het tweede hoofdstuk wordt een schema van 8 kleurklassen gegeven waarvan enkele fysiologische hoedanigheden zijn vastgesteld. Om de algemene geldigheid van het schema te toetsen zijn de proeven uitgevoerd met zowel groene, als half-groene en bleke rassen. Omdat uit voorbereidende proeven was gebleken dat het eerste stadium, de zogenaamde rijpgroene fase, niet goed te onderkennen is en gevoelig is voor Botrytis, is het in de meeste proeven niet opgenomen.

Kleurmetingen aan gehomogeniseerde vruchten middels de Hunterlab Model D-25 Color and Color Difference Meter en zachtheidsmetingen met de, in het eerste hoofdstuk beschreven, zachtheidsmeter toonden duidelijke en reproduceerbare verschillen tussen tomaten van de verschillende kleurfasen.

Het soortelijk gewicht blijkt toe te nemen naarmate de rijping vordert. Voor vruchten van de verschillende kleurklassen bestaan duidelijke verschillen in soortelijk gewicht.

Aan individuele vruchten werd het verloop van de ademhaling bepaald. Het ademhalingsverloop blijkt parallel te gaan met de inwendige ethyleenconcentratie. Beide processen tonen de sterkste intensiteit in hetzelfde kleurstadium, zijnde het stadium voordat de vrucht geheel oranje gekleurd is (stadium 5). Het ademhalingsquotiënt is vrijwel gelijk aan 1.

Bovengenoemde meetresultaten blijken niet afhankelijk te zijn van de diverse getoetste cultivars. Het in het tweede hoofdstuk behandelde schema van kleurfasen mag daarom verondersteld worden te zijn een onderverdeling van het rijpingsproces in enkele fysiologisch goed te onderscheiden fasen.

De relatie tussen tomateplant en -vrucht is het onderwerp van het derde hoofdstuk.

Vegetatieve plantedelen blijken invloed te hebben op de groei van de tomaat, waarbij vooral de verhouding van het aantal bladen tot het aantal vruchten bepalend is. Geconstateerd werd een positief verband tussen gewicht en volume van de vruchten enerzijds en het per vrucht beschikbare bladoppervlak anderzijds. De kg. opbrengst per plant wordt echter bepaald door het aantal vruchten per tros.

De blad : vrucht verhouding blijkt geen invloed uit te oefenen op de snelheid van ontwikkeling van de vruchten. Er zijn bijgevolg dus geen verschillen in tijdsverloop tussen bestuiving en pluk.

Tussen de blad : vrucht verhouding enerzijds en de inwendige ethyleenconcentratie, de zachtheid en het ascorbinezuurgehalte van de vruchten anderzijds kon geen verband worden aangetoond.

Een blad : vruchtverhouding van 3 : 1 geeft vruchten van een grote uniformiteit. Voorts werd waargenomen dat, naarmate het gemiddelde bladoppervlak per vrucht toeneemt, de kans op vruchten met een groen tot geel-groen gekleurd loculair weefsel groter wordt.

Dit is een afwijking van het normale rijpingspatroon. Wanneer een tomaat normaal rijpt, loopt de kleuring van het loculaire weefsel parallel aan die van het pericarp, d.w.z. van groen naar rood. Zaden uit in kleur afwijkend loculair weefsel blijken minder kiemkrachtig te zijn dan die uit normaal gekleurd loculair weefsel. Het ascorbinezuurgehalte van vruchten met abnormaal gekleurd loculair weefsel is hoger dan normaal.

De snelheid van ontwikkeling van vruchten aan de tros blijkt de tendens te hebben tot achterblijven op die van in stadium 2 afgeplukte tomaten onder overigens gelijke omstandigheden van temperatuur en luchtvochtigheid. De verschillen werden niet groot genoeg bevonden om definitief een uitspraak te doen over de invloed van de plant op de snelheid van vruchtontwikkeling. Tussen geplukte en niet geplukte vruchten van gelijke kleurfase kan geen verschil worden aangetoond in hoedanigheden als inwendige ethyleenconcentratie, zachtheid, aantal zaden en ascorbinezuur-gehalte.

De locatie aan de tros gaf geen aanleiding tot verschillen in ontwikkelingssnelheid van de vruchten. De eerste vruchten aan de tros zijn doorgaans niet de grootsten. Slechts in 50-60% van de gevallen wordt de bloem welke het dichtst bij de plantenstengel zit eerder bestoven en de vrucht daarvan is dus eerder rijp dan de vrucht van de eerstvolgende bloem.

Bij dezelfde blad : vruchtverhouding is het aantal zaden positief gecorreleerd met het vruchtgewicht en een langere groeiperiode van de vruchten. Toch blijkt bij een toenemend aantal vruchten per bladoppervlak het aantal levensvatbare zaden toe te nemen, ten gevolge van zaadabortie bij een hogere blad : vruchtverhouding.

Het kelkgedeelte van de vrucht heeft over het algemeen meer zaden dan het gedeelte aan de steelkant. De hokken van een vrucht blijken nooit gelijk van grootte en nooit hetzelfde aantal zaden in te houden. Dit blijkt het gevolg te zijn van een verschil in eicel-bezetting van de hokken en is dus een verschijnsel dat tijdens de bloemaanleg zijn beslag vindt.

Zowel het niet op kleur komen van het loculaire weefsel als het minder kiemkrachtig zijn van de zaden in vruchten van planten met een grotere blad : vruchtverhouding wijzen op de aanwezigheid van een stof die de rijping tegengaat. Deze stof zou een gibberelline kunnen zijn. Een veronderstelling die wordt gesteund door onze waarneming dat bij een grotere blad : vruchtverhouding zaden aborteren.

Wanneer echter de planten de tomatevruchten zouden voorzien van een stof die de rijping tegengaat dan moeten geplukte vruchten sneller afrijpen dan niet geplukte. Dit kon in onze proeven niet duidelijk bevestigd worden. Deze proeven werden afgesloten wanneer de vruchten het oranje gekleurde stadium 6 hadden bereikt. De mogelijkheid blijft dus open dat in een later stadium, wanneer het metabolisme van de vruchten in activiteit afneemt, de invloed van de plant op de vruchten wel merkbaar wordt.

Het duurt doorgaans enige tijd voordat geplukte tomaten de consument bereiken en het is dus van belang te weten wanneer geplukt moet worden. In het hoofdstuk IV worden daarom enige fysiologische en anatomische aspekten van het pluktijdstip besproken.

Door toepassing van een speciale methodiek kan de volumevermeerdering van tomaten tijdens de rijping aan de plant fotografisch worden aangetoond.

De toenamen van het soortelijk gewicht en het zachter worden van tomaten tijdens de rijping wijzen op anatomische veranderingen in de vrucht. De electronenmicroscoop bevestigde deze veronderstelling, waarvan in dit hoofdstuk enige fotografische weergaven. De structuur van de parenchymcellen in het pericarp blijkt tijdens de rijping te veranderen. Door de oplossing van pectinen in de celwanden verliezen de cellen hun oorspronkelijke stevigheid en worden samengedrukt, met als gevolg dat de intercellulairen kleiner worden. Deze gang van zaken heeft zowel bij geplukte als bij niet geplukte vruchten het zelfde resultaat, nl. een toename van het soortelijk gewicht. Deze toename is echter niet op dezelfde wijze tot stand gekomen.

Bij geplukte vruchten is het gewichtsverlies gering. Het verlies aan volume is groter waardoor het s.g. stijgt tijdens de rijping. Niet-geplukte vruchten krijgen tijdens het rijpingsproces water en voedingsstoffen toegevoerd waardoor het gewicht toeneemt. Door de structuurveranderingen van de cellen in het pericarp is de toename van het volume niet meer evenredig aan de gewichtsvermeerdering, maar kleiner waardoor het s.g. stijgt. Het plukken van vruchten in een later stadium van rijpheid zou daardoor een hogere opbrengst moeten geven. Dit werd bevestigd in praktijkproeven waarbij de kg opbrengst van groen geplukte tomaten (stadia 2 t/m 4) vergeleken werd met die van rood geplukte (stadium 5 en 6) vruchten.

Bovendien is de houdbaarheid van in een later stadium geplukte vruchten beter door een grotere weerstand tegen Botrytis aantastingen en lage temperatuurbederf.

Een merkwaardig feit is dat tomaten geplukt in de kleurstadia 2 t/m 6 en opgeslagen bij 19°C in dezelfde tijd rijpen tot stadium 8. Dat wil zeggen dat hoe meer de tomaat gekleurd is bij de pluk hoe langzamer de rijping daarna verloopt.
Dit zou erop wijzen dat tijdens de rijping de plant aan de vruchten een stof afgeeft welke de rijping tegengaat, maar waarvan de werking pas merkbaar wordt wanneer het oranje kleurige stadium 6 is bereikt en het metabolisme van de vrucht minder actief wordt. Hoe rijper de vrucht bij de pluk hoe langer de shelf life is. Shelf life is hier gedefinieerd als de tijd gedurende welke de vruchten vrij van pathogene aantastingen en eetbaar zijn tijdens opslag bij 19°C en een r.v. van 88%. Als minimum eis werd gesteld dat de shelf life 3 dagen zou duren.

De kwaliteit van 's morgens vroeg en die van 's middags geplukte vruchten werden gedurende meerdere jaren vergeleken. De tomaten werden onder verschillende omstandigheden van temperatuur en luchtvochtigheid opgeslagen. Er werden geen verschillen in kwaliteit geconstateerd. Wanneer de teeltmaatregelen zodanig zijn dat overdag geen vochtverliezen van de vruchten kunnen optreden, dan is het plukken van tomaten gedurende de gehele dag mogelijk zonder verlies aan kwaliteit.

Samenvattend kan geconcludeerd worden dat plukken in een later stadium van de rijping een grotere oogst van betere kwaliteit geeft, waarbij het tijdstip op de dag van plukken geen rol speelt.

Het gedrag van de tomaat na de oogst onder verschillende omstandigheden wordt in het laatste hoofdstuk behandeld. Dit gedrag wordt bepaald door het rijpheidsstadium bij de pluk, de temperatuur en de relatieve vochtigheid tijdens de opslag en de atmosferische samenstelling in de opslagruimte.

De temperatuur is een van de belangrijkste factoren die de kwaliteit van de geplukte tomaat beinvloeden. Het optimale temperatuurtraject voor de rijping van tomaten is 19 - 20°C. Lagere temperaturen vertragen het verloop van de rijping. De beste temperatuur voor deze vertraging is 12,5 - 13°C. Beneden deze temperatuur is het verband tussen het aantal dagen opslag bij lagere temperatuur enerzijds en de rijpingstijd resp. het optreden van rotvorming anderzijds rechtlijnig. Hoe lager de temperatuur hoe langduriger de vertraging en hoe sneller rotvorming optreedt. Opslag van vier dagen bij 0°C of 12 dagen bij 12°C, gevolgd door 19°C, geven dezelfde totale afrijpingstijd van ongeveer 17 dagen.

De luchtvochtigheid is een tweede belangrijke factor voor de kwaliteit van de tomaat gedurende de rijping. Een relatieve vochtigheid van 88% is te hoog, waardoor grote verliezen door rotvorming optreden. Een relatieve vochtigheid van 72% gaf in de proeven, vooral bij de meer groene kleurklassen 2 en 3, de minste aantallen door Botrytis aangetaste vruchten. Hoe rijper de tomaat geoogst wordt, hoe minder de uitwendige omstandigheden invloed hebben op de kwaliteit waardoor zowel de kans op het bereiken van enig shelf life als de duur ervan groter worden.

De conclusie is hier ook weer dat het plukken van tomaten in een later rijpingsstadium dan vaak in de praktijk gebeurt, meer zekerheden biedt t.a.v. een goede kwaliteit van het geoogste produkt.
De bewaarduur van tomaten bij een temperatuur van 12,5 - 13°C is ongeveer 14 dagen.

C.A. bewaring geeft geen verlenging van deze periode, vooral door het optreden van Botrytis rot. In enkele proefjes ter voorkoming van deze aantasting werden goede resultaten verkregen door de vruchten vóór de opslag te dompelen in een oplossing van 100 ppm pimaricine.

De bewaarduur van tomaten werd aanzienlijk verlengd door toepassing van bewaring onder verlaagde atmosferische spanning. Het is voornamelijk de verlaging van de partiële zuurstofspanning waardoor deze verlenging wordt bereikt.

Wageningen, 1 december 1975
NS/LvH

CURRICULUM VITAE

Na het behalen van het einddiploma HBS[B] in 1941 begon de auteur de studie aan de Landbouwhogeschool te Wageningen. Onderbroken door de oorlog, werd deze studie in de richting Tr.L 1 in 1945 hervat en in april 1949 afgesloten.

Na werkzaamheden in Indonesië volgden aanstellingen bij de Plantenziektekundige Dienst te Wageningen en Wiersum Chemie te Groningen. In 1965 werd de auteur benoemd tot wetenschappelijk ambtenaar bij het Sprenger Instituut te Wageningen.