INFLUENCE OF DIFFERENT RATES AND INTENSITIES OF LIGHT ON SOLANINE CONTENT AND COOKING QUALITY OF POTATO TUBERS

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1. INTRODUCTION

Solanine in small amounts is regarded as a normal constituent of potato tubers, and is probably partly responsible for their characteristic flavour. In greater quantities, solanine, a glycoalkaloid, will give the tubers a bitter taste, and, under very unfavourable circumstances, a toxic level may be reached. (ALFA and HEYL, 1923; BOMER and MATTIS, 1924; GRIEBEL 1924). Because of the influence of the compound on the cooking quality, considerable work has been done to elucidate the variation in the solanine content between varieties (WOLF and DUGGAR, 1946; LEPPER, 1947). The effect of the metabolic stage of tubers (HILTON and GAMBORG, 1957), as well as a number of environmental and other factors on the solanine content, has also been investigated (MORGENSTERN, 1907; SCHOWALTER and HARTMANN, 1924; PALLMANN and SCHINDLER, 1942; BURTON, 1948; HUTCHINSON and HILTON, 1955).

Although the fact that light often increases the solanine content has been confirmed in several investigations (MORGENSTERN, 1907; BØMER and MATTIS, 1924; GRIEBEL, 1924; KRÖNER and VÖLKSEN, 1950; HILTON and GAMBORG, 1957), rather scanty information seems to be available concerning the rates of light to which the tubers can be exposed without a serious increase in solanine. During the harvest, some exposure to light will always occur. By use of harvesting machines, digging some time in advance of picking, the rates of light to which the tubers are exposed may be considerable. Increasing quantities of the potatoes marketed today are washed, and packed in semi-transparent bags. The risk of the tubers being exposed to greater rates of light on their way from producer to consumer, will in this way certainly be greater.

The main objectives of the experiment described in this paper have been:

a. To get more precise knowledge about the rates of light to which the tubers can be subjected without serious increases in the solanine content.

b. To investigate the relationship between cooking quality, as evaluated by organoleptic tests, and the solanine content of the tubers, or the rates of light to which the tubers have been exposed.

2. MATERIALS AND METHODS

Tubers of the variety *Kerr's Pink* were exposed to light for definite time intervals, and the rates of light received by the samples during the different periods of exposure

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were measured. A sensitive luxmeter, connected with a compensation writer, was employed for the measurement. By reading the range of the luxmeter scale, and the velocity of the writer, the rates of light to which the samples had been exposed could be calculated accurately at any time during the experimental period.

In the first series of the experiment, the tubers were stored outdoors and exposed to direct, or in cloudy weather, indirect sunlight. Samples for analysis were taken after 2, 4, 6, 24, 48, nad 72 hours.

In the second series, the samples were stored indoors, and exposed to a weak, indirect light. A few samples received additional light from incandescent lamps for a period of 60 hours. Tubers for analysis were collected after 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 14, 18, and 22 days. The light intensity was far greater in the first than in the second series.

In a third series, the solanine content of 9 varieties was investigated, after exposure of the tubers to light for a given time. In all cases, the samples were exposed to light simultaneously, and the storage time was measured continuously from the start, comprising both days and nights.

The tubers were spread out in a single layer, all of them thus being exposed to light. To minimize the error, care was taken to expose the samples to as little light as possible before and after the experimental period. Only freshly dug tubers, which at the outset showed no sign of greening, were used in the experiment.

The samples used for analysis contained 5 tubers, the sample weight being 500–600 g.

Composition of samples:

No. of tubers	1	2	1	1
Weight, g	50–80	80–100	120–150	150–180

Two separate samples were taken for analysis at each sampling. In the variety series larger samples were used.

It would probably have been of advantage to use larger samples and more narrow class limits, but a heavy attack of late blight during the experimental period and the subsequent storage period reduced the number of fresh tubers available for analysis.

The contents of solanine plus solanidine of the tubers were determined by an analytical method described by BAKER, LAMPITT, and MEREDITH (1955). The treatment period was finished by October 17, and the samples were analysed between November 5, 1961, and January 30, 1962. In the period between treatment and analysing, the samples were stored at 3 °C in a dark room. The results indicate that no major changes in the solanine content occurred during the storage, but the possibility of smaller changes taking place should not be ruled out.

3. LIGHT, HUMIDITY, AND TEMPERATURE

3.1. *Outdoor storage*

The first day was cloudless. Between 9 a.m. and 3 p.m., when the first 3 samples were taken, the light intensity varied between 35.000 and 50.000 lux. The second day was

cloudy, maximum light being about 25.000 lux, while the third day was partly cloudy, the intensity of light varying between 10.000 and 60.000 lux.

The temperature and humidity of the air were measured by the use of a thermohydrograph. The relative humidity varied between 55 and 100 per cent, and the temperature between 5 and 25 °C.

3.2. *Indoor storage*

Total variation in light intensity was 0 to 30 lux. The incandescent lamps yielded 25 lux, and were used for 60 hours in the period between the 9th and the 12th day of storage.

Average temperature of the air was 18 °C, with variations from 15 to 20 °C. The relative humidity averaged 55 per cent, the total variation being 45 to 75 per cent.

4. INFLUENCE OF DIFFERENT RATES OF LIGHT ON THE SOLANINE CONTENT

4.1. *Outdoor storage*

Storage of the tubers for 2 or 4 hours in bright sunlight (35.000–50.000 lux) resulted in only minor changes in the solanine content. A significant increase occurred, however, during 6 hours storage, in washed as well as in brushed tubers. Still longer exposure generally resulted in a further increase in solanine, although the samples of washed tubers at 48 hours represent an exception (fig. 1).

The relationship between the rates of light received and the solanine content was highly significant. During the first 24 hours, the solanine content was consistently higher in washed than in brushed tubers, indicating that the thin layer of dust on the surface of brushed tubers offers some protection against light. The results at 72 hours have not been included, because of the wide variations between replicates.

The increase in solanine has taken place predominantly in the outer layers of the tuber. Already after 4 hours storage, a significant increase was evident in the peel (0–2 mm), and the synthesis of solanine continued throughout the experimental period. The correlation between light received and solanine in the peel was very high. $r = 0{,}96^{***}$.

For the layer 2–10 mm, as well as the pith, a significant, positive relationship between light and solanine was found, $r = 0{,}91^{**}$ and $0{,}86^{*}$, respectively. As will be seen from FIG. 2, however, the increase in the solanine content was moderate in these tissues at all samplings, and especially low in the pith.

WOLF and DUGGAR (1946) found that the solanine content in normal tubers varied between 1 and 15 mg per 100 g of fresh weight. BÖMER and MATTIS (1924) obtained similar results, and they suggested 20 mg as an upper limit of safety for food. LEPPER (1949) reported that a bitter taste was evident when the content of solanine exceeded 10 mg per 100 g of fresh weight.

Variation of solanine in tubers that had not been exposed to light was in this experiment 4,0–8,1 mg. The suggested limit of safety, 20 mg, was exceeded after 6 hours

FIG. 1. Solanine contents of washed and brushed tubers, and rates of light received at different sampling times

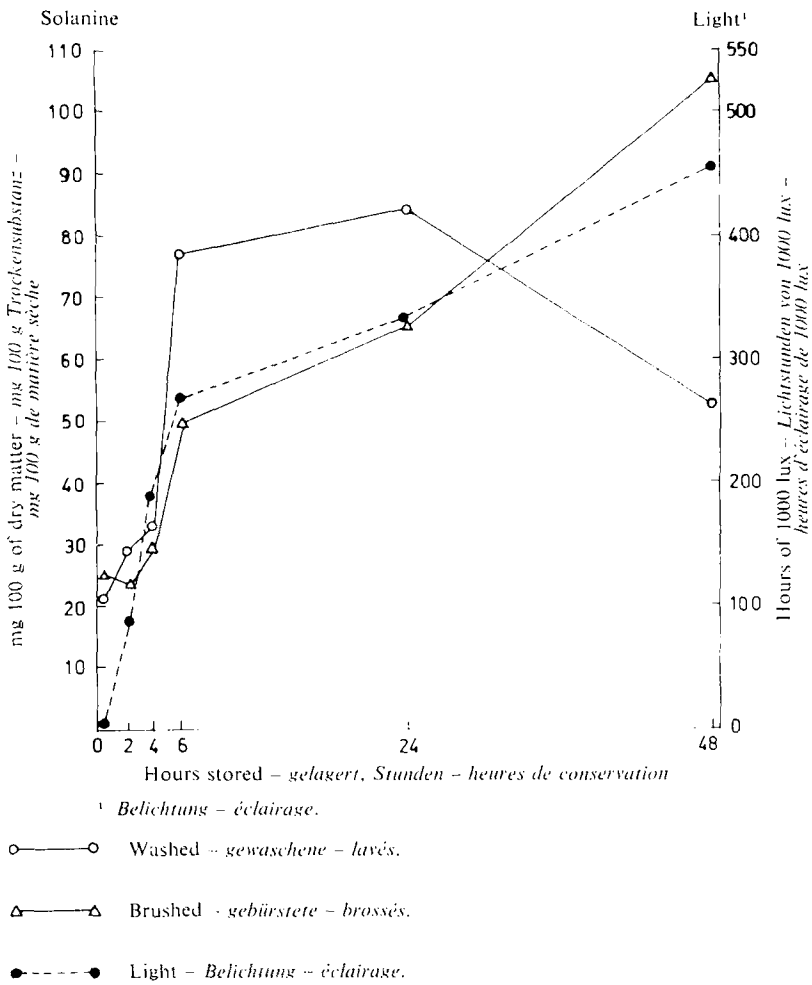

ABB. 1. *Solaningehalt gewaschener und gebürsteter Knollen, und die in verschiedenen Zeiten der Probenahme verabreichten Lichtgaben*

FIG. 1. *Teneur en solanine des tubercules lavés et brossés, et doses de lumière reçues aux différents moments d'échantillonnage*

exposure to bright sunlight for washed tubers, and after two days storage for brushed tubers.

When referring to earlier values it should be remembered that the methods of solanine determination seldom have been the same in the different experiments. The results, therefore, are not strictly comparable. There are indications that by the analytical

FIG. 2. Solanine contents in different parts of the tuber, and rates of light received at different sampling times

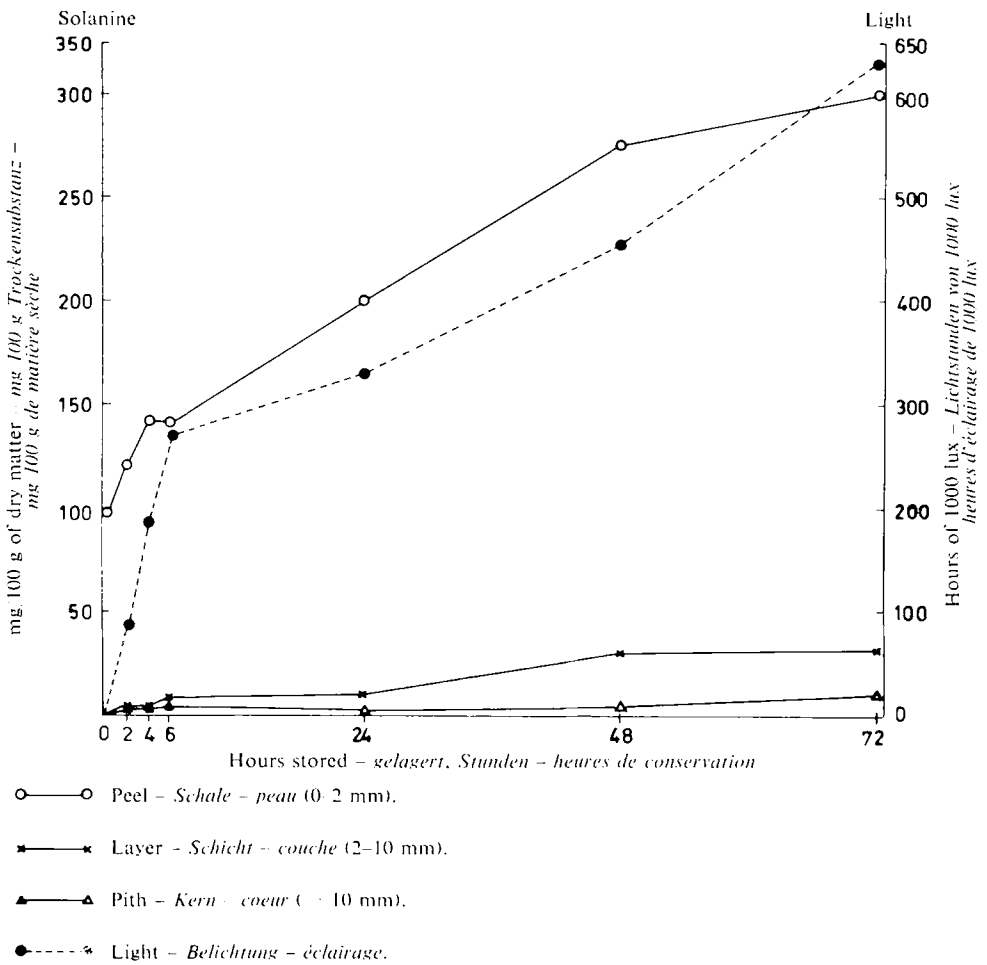

ABB. 2. *Solaningehalt in verschiedenen Teilen der Knolle sowie die in verschiedenen Zeiten der Probenahme verabreichten Lichtgaben*

FIG. 2. *Teneur en solanine de différentes parties du tubercule, et doses de lumière reçues aux différents moments d'échantillonnage*

method used in the investigation reported, the quantities of solanine extracted will be greater than by most methods employed earlier (BAKER *et al.*, 1955).

4.2. *Indoor storage*

The increase in solanine in the weak light used indoors, was insignificant, even after 22 days of storage. The samples, which in the middle of the storage period were ex-

posed to light from incandescent lamps for 60 hours, turned green, but only negligible changes occurred in solanine.

It should be kept in mind that the rates of light received during the indoor storage were small. During the 22 days of indoor storage the tubers were exposed to less light than were samples exposed to bright sunlight for half an hour (table 1).

TABLE 1. Solanine in tubers; in mg/100 g of dry matter, average of 2 replicates

Material examined *Untersuchtes Material* *Matière analysée*	Solanine after 0–22 days of indoor storage *Solanin nach 0–22 tägiger Aufbewahrung im Lagerraum* *Solanine après conservation à l'intérieur pendant 0–22 jours*													
	0	1	2	3	4	5	6	7	8	9	10	14	18	22
Whole tubers[1]														
washed[2]	21	25	24	27	25	30	23	33	23	33	30	36	35	30
brushed[3]	25	32	24	39	33	27	33	32	31	33	33	31	29	28
Washed tubers[1]														
0–2 mm layer[5]	97	164	188	175	208	144	185	197	207	209	204	197	206	224
2–10 mm layer[5]	2	8	8	8	14	5	4	4	9	11	9	10	11	8

[1] *Ganze Knollen – tubercules entiers.*
[2] *Gewaschene – lavés.*
[3] *Gebürstete – brossés.*
[4] *Gewaschene Knollen – tubercules lavés.*
[5] *In der 0–2 mm bzw. 2–10 mm Schicht – dans la couche de 0–2 mm respectivement de 2–10 mm.*

TABELLE 1. *Solaningehalt der Knollen; in mg/100 g Trockensubstanz, Mittel von 2 Wiederholungen*
TABLEAU 1. *Teneur en solanine des tubercules; en mg/100 g de matière sèche, moyenne de 2 mesures répétées*

5. CONTENTS OF SOLANINE IN DIFFERENT VARIETIES

Few data are available concerning the solanine content of the varieties commonly used in Norway. Nine varieties were therefore analysed for solanine, after having been stored outdoors for 3 days (72 hours). During this period they received light equivalent to 539 hours of 1000 lux. Chlorophyll formation was visible in all yellow-skinned varieties at the end of the storage period. There were, however, considerable varietal differences in the intensity of the green colour.

Composition of samples:

No. of tubers	5	5	2
Weight, grams	30–60	60–90	90–120

The differences in solanine content between varieties are very great (table 2). Most of the varieties could be exposed to considerable rates of light without reaching the suggested, dangerously high level of solanine (BÖMER and MATTIS, 1924). The level at which an off-flavour is noticeable, however, is reached or approached by most of the varieties tested. The data strongly suggest that great varietal differences exist with respect to the increase in solanine upon exposure to higher rates of light. This would be in accordance with results obtained in earlier investigations (SVENSSON, 1962).

TABLE 2. Solanine in tubers of different varieties stored outdoors for 72 hours, in mg/100 g of material analysed

Variety *Sorte* *Variété*	In dry matter *In Trockensubst.* *En matière sèche*	In fresh tubers *In frischen Knollen* *En tubercules frais*	Variety *Sorte* *Variété*	In dry matter *In Trockensubst.* *En matière sèche*	In fresh tubers *In frischen Knollen* *En tubercules frais*
Jøssing	17,1	4,2	Kerr's Pink	48,6	13,6
Libertas	26,7	6,8	Pimpernell	50,4	15,3
Furore	33,3	9,2	King George	79,4	18,7
Ås	36,1	9,6	Prestkvern	126,0	34,5
Gineke	37,6	9,6			

TABELLE 2. *Solaningehalt in den Knollen verschiedener Sorten nach einer Lagerung von 72 Stunden im Freien, in mg/100 g des untersuchten Materials*

TABLEAU 2. *Teneur en solanine des tubercules de différentes variétés après conservation en plein air pendant 72 heures, en mg/100 g de matière analysée*

6. RELATION BETWEEN SOLANINE CONTENT AND COOKING QUALITY

Flavour and surface discoloration were evaluated by organoleptic tests. The tubers were peeled after boiling. No salt was added to the samples. The testing took place at the State Research Institute in Home Economics, Stabekk, each sample being graded by five judges. Scores ranging from 1 to 10 were given for the quality factors, 1 designating the lowest quality (table 3).

TABLE 3. Characteristics of the scores for two quality factors

	Scores – *Bewertungszahlen – chiffres d'appréciation*				
	1–2	3–4	5–6	7–8	9–10
Surface discoloration *Verfärbung der Oberfläche* *Décoloration superficielle*	Very strong *Sehr stark* *Très forte*	Strong *Stark* *Forte*	Moderate *Mässig* *Moyenne*	Slight *Leicht* *Faible*	None *Keine* *Aucune*
Flavour *Geschmack* *Goût*	Bad *Schlecht* *Mauvais*	Rather bad *Zieml. schlecht* *Médiocre*	Fair *Zieml. gut* *Passable*	Good *Gut* *Bon*	Very good *Sehr gut* *Excellent*

TABELLE 3. *Kennzeichen der Bewertungszahlen für zwei Qualitätsfaktoren*

TABLEAU 3. *Caractéristiques des chiffres d'appréciation de deux facteurs de qualité*

Storage of freshly dug tubers for 2 or 4 hours in bright sunlight resulted in only minor changes in the cooking quality. After 6 hours storage under the same conditions, a considerable aggravation of the quality was registered. During this 6-hour period, the solanine content increased from 5 to 20 mg per 100 grams of fresh weight. Further exposure to light resulted in a serious deterioration of the cooking quality. Significant, negative relationships were found between light and flavour, and likewise between solanine and flavour, $r = -0{,}91^{**}$ and $-0{,}95^{**}$, respectively (FIG. 3).

No changes occurred in cooking quality during 8 days of indoor storage with light intensities ranging from 0 to 30 lux. Further exposure for 60 hours to incandescent lamps, yielding 25 lux, deteriorated the flavour considerably, and the colour still

FIG. 3. Relation between flavour and surface discoloration and the length of the outdoor storage

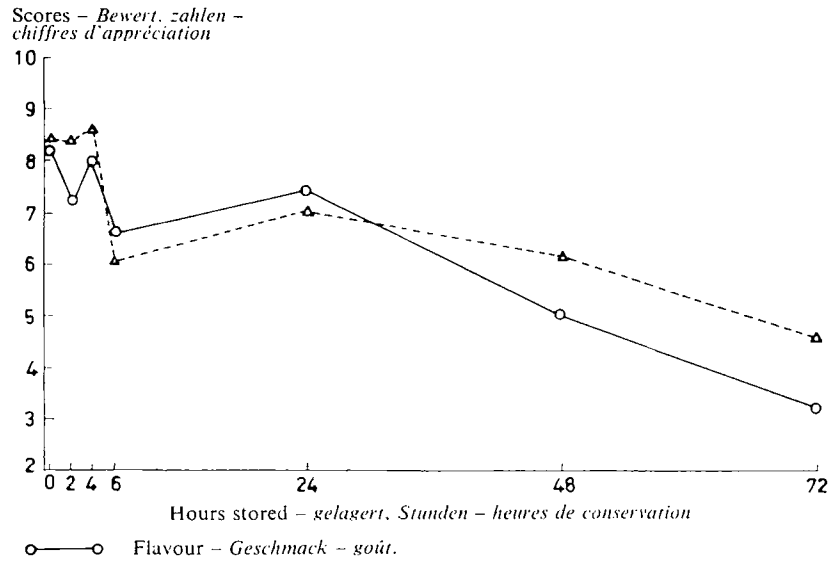

ABB. 3. *Verhältnis zwischen Geschmack und Verfärbung der Oberfläche und der Dauer der Lagerung im Freien*

FIG. 3. *Rapport entre le goût et la décoloration superficielle et la durée de la conservation en plein air*

more. Since only insignificant changes occurred in the solanine content, other factors must be responsible for the decrease in quality. Greening of the tubers was evident at the end of the storage under artificial light, and there is a possibility that chlorophyll is also partly responsible for the deterioration in flavour.

For the whole period, 22 days, a significant, negative correlation, $r = -0{,}64^*$, was found between light and flavour also at the low light intensities used during the indoor storage.

SUMMARY

Storage of freshly dug potato tubers for 2 or 4 hours in bright sunlight resulted in only minor changes in the solanine content. A significant increase in solanine in tubers exposed to intense light for 6 hours was registered. The cooking quality had been deteriorated somewhat during the same period. Further exposure resulted in a gradual increase in the solanine content, and a serious deterioration of the cooking quality.

During 22 days of storage indoors, in weak light, only small changes in the solanine content occurred, but the quality was lowered in samples stored for more than 10 days. Chlorophyll formation was evident in samples exposed part of the time to light from incandescent lamps.

The increase in solanine upon exposure to light was very great in the peel, moderate in the cambium layer (2–10 mm) and insignificant in the pith.

Washed tubers were more susceptible to light than brushed ones.

Great varietal differences in the solanine content were found.

ZUSAMMENFASSUNG

EINFLUSS VERSCHIEDENER LICHTGABEN UND LICHTINTENSITÄTEN AUF DEN SOLANINGEHALT UND DIE SPEISEQUALITÄT VON KARTOFFELKNOLLEN

Der Zweck der gegenwärtigen Forschungsarbeit ist weitere Aufschlüsse über die Lichtgaben (Intensität × Zeit) zu geben, welchen Kartoffelknollen ausgesetzt werden können, ohne dass diese die Speisequalität merklich beeinträchtigen würden. In der einen Versuchsreihe wurden die Knollen 2, 4, 6, 24, 48 und 72 Stunden im Freien, in einer zweiten Reihe 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 14, 18 und 22 Tage in einem Lagerraum aufbewahrt. Bei der Lagerung im Freien war die erreichte maximale Lichtintensität 60.000 Lux, während bei der Aufbewahrung im Lagerraum diese niemals 30 Lux überschritten hatte. Durch die Anwendung eines empfindlichen Belichtungsmessers, welcher an ein zusätzliches Schreibgerät angeschlossen war, konnte man jederzeit die Lichtgaben messen, welchen die Knollen im Laufe der Versuchszeit ausgesetzt waren. Für den Lagerungsversuch wurden Knollen der Kartoffelsorte *Kerr's Pink* verwendet.

In einer dritten Versuchsreihe wurde der Solaningehalt an 9 Kartoffelsorten einem Studium unterzogen.

Angaben über die Zusammensetzung der für die Analyse benützten Proben finden wir im Text. Zur Bestimmung des Solaningehaltes wurde die analytische Methode angewandt, die bei BAKER *et al.* (1955) beschrieben ist.

Die ABBILDUNGEN 1. und 2., sowie die TABELLE 1. veranschaulichen den Einfluss des Lichtes auf den Solaningehalt der Knollen. Frischgerodete Knollen konnten 2 bis 4 Stunden lang intensivem Licht ausgesetzt werden, ohne dass dies im Solaningehalt oder in der Speisequalität wesentliche Veränderungen hervorgerufen hätte. Nach 6 Stunden wurde eine beträchtliche Steigerung des Solaningehaltes wahrgenommen, wobei sich zugleich auch eine mässige Qualitätsverschlechterung zeigte. Eine noch längere Exposition führte im allgemeinen zu einer weiteren Erhöhung des Solaningehaltes und zu einer bedeutenden Verschlechterung der Qualität (ABB. 3).

Die Lagerung durch 22 Tage bei schwachem Licht hatte keinen merklichen Einfluss auf den Solaningehalte, die Proben jedoch, welche einen Teil dieser Zeit (60 Stunden) schwachem künstlichen Licht (25 Lux) ausgesetzt waren, sind grün geworden. Während dreitägiger Lagerung im Freien wurde keine Chlorophyllbildung beobachtet, selbst dann nicht, wenn die Proben viel mehr Licht erhielten, wie die im geschlossenen Raume gelagerten Knollen.

Gewaschene Knollen waren gegenüber Licht empfindlicher, wie die nur gebürsteten (ABB. 1.). Bei den verschiedenen Sorten zeigten sich im Solaningehalt grosse Unterschiede (TABELLE 2.).

RÉSUMÉ

INFLUENCE DE DIFFÉRENTES DOSES D'ÉCLAIRAGE ET DIFFÉRENTS NIVEAUX D'ÉCLAIREMENT SUR LA TENEUR EN SOLANINE ET LA QUALITÉ CULINAIRE DES TUBERCULES DE POMME DE TERRE

La présente étude vise à mieux connaître les doses d'éclairage (éclairement × temps) auxquelles les tubercules de pomme de terre peuvent être exposés sans détérioration appréciable de la qualité culinaire. Dans une série d'essais, des échantillons de tubercules furent conservés en plein air pendant 2, 4, 6, 24, 48 et 72 heures; dans la seconde série, ils furent conservés à l'intérieur pendant 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 14, 18 et 22 jours. Pendant la conservation en plein air, l'éclairement maximal fut de 60.000 lux, tandis que l'éclairement pendant la conservation à l'intérieur ne dépassa jamais 30 lux. L'emploi d'un photomètre sensible combiné avec un enregistreur à compensation permit de mesurer les doses de lumière que les tubercules avaient reçu à tout moment de la période d'essai. L'essai de conservation fut exécuté avec des tubercules de la variété *Kerr's Pink*.

La teneur en solanine de 9 variétés fut étudiée dans une troisième série.

Les données relatives à la composition des échantillons sont mentionnées dans le texte. Une méthode d'analyse décrite par BAKER *et al.* (1955) fut appliquée pour la détermination de la solanine.

L'influence de la lumière sur la teneur en solanine des tubercules est illustrée par les FIGURES 1 et 2 et le TABLEAU 1. Des tubercules nouvellement déterrés furent exposés à un éclairage intense pendant 2 à 4 heures sans qu'il se produisit de changement important de la teneur en solanine ni de la qualité culinaire. Après 6 heures, une augmentation considérable de la solanine fut enregistrée en même temps qu'une baisse modérée de la qualité. En général, une exposition encore plus longue provoquait une augmentation supplémentaire de la teneur en solanine et une grave détérioration de la qualité (FIG. 3).

La conservation pendant 22 jours à la lumière faible n'influençait pas considérablement la teneur en solanine, mais les échantillons ayant passé une partie de cette période (60 heures) sous un éclairage artificial de faible intensité (25 lux) verdirent. Aucune formation de chlorophylle ne fut observée pendant 3 jours de conservation en plein air, même lorsque les échantillons recevaient beaucoup plus de lumière que les échantillons conservés à l'intérieur.

Les tubercules lavés étaient plus sensibles à la lumière que ceux qui avaient uniquement été brossés (FIG. 1). Il fut observé de fortes différences de la teneur en solanine d'une variété à l'autre (TABLEAU 2).

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