ISSN 0300 — 9254

JOURNAL OF THE NATIONAL SCIENCE COUNCIL OF SRI LANKA

VOLUME 2 No. 1 JUNE 1974

Journal of the National Science Council of Sri Lanka

PUBLICATION: One volume of two issues (June and December) is published annually by the National Science Council of Sri Lanka.

Subscription

Annual subscription—Foreign $ 8.00 ; Local Rs. 15.00. Accepted on a calendar year basis. Rates include postage.

Single issues and available back issues—Foreign $ 4.00; Local Rs. 7.50 each. Rates include postage.

Payment must accompany all orders. Remittances in favour of National Science Council of Sri Lanka.

Change of address notice is required 4 weeks before issue date.

Manuscripts

Research Papers, Reviews and Short Communications in all fields of Science and Technology in Sinhala, Tamil and English may be submitted for editorial consideration. Manuscripts should conform to the style adopted in this issue. For instructions as to preparation of papers see inset at back of this issue. Separates of General Instructions and Special Instructions in Chemical, Physical and Medical Sciences may be had on application to the Secretary, Editorial Board at the address given below.

No responsibility is assumed by the National Science Council of Sri Lanka for statements and opinions expressed by the contributors to this Journal.

Manuscripts, Orders and all correspondence relating to the Journal should be sent to :

The Secretary,
Editorial Board,
Journal of the National Science Council of Sri Lanka,
47/5 Maitland Place,
Colombo 7,
SRI LANKA.

Printed at Sri Lanka University Press, Katubedde

J. Natn. Sci. Coun. Sri Lanka 1974 2(1) : 1-11.

The Influence of Cold Storage on the Survival and Flowering of Field Planted Cabbage, Carrot and Beet in Sri Lanka

Y. D. A. SENANAYAKE

Department of Crop Science, University of Sri Lanka, Peradeniya Campus, Peradeniya, Sri Lanka.

(*Paper accepted*: 14 *March* 1974)

Abstract : An investigation was conducted to determine the influence of the storage of cabbage, carrot and beet plants at low temperatures (0.5 to 1.0°C and 7.0 to 8.5°C) for different durations (15 days to 60 days) on their flowering when they were subsequently planted in the field at two locations in Sri Lanka having different elevations (Kundasale, 450 m and Nuwara Eliya, 1,850 m).

The results indicate that all the cabbage plants that were pre-stored at 0.5 to 1.0°C for 40 days flowered when they were planted at Nuwara Eliya. Only a maximum of 57.14% flowered at Kundasale. Carrots stored at the same temperature for 50 days gave the best response (18% flowering) when grown at Kundasale. The survival of the plants at a location was associated with the incidence of rainfall after field planting. The lower mean temperature at Nuwara Eliya promoted flowering and the development of the normal inflorescences in cabbage while it suppressed flowering in carrot. The higher mean temperature at Kundasale promoted flowering in carrots and partially inhibited flowering in cabbage and suppressed the development of normal inflorescences. Beet did not respond to the treatments.

1. Introduction

Biennial, exotic vegetables like cabbage, *Brassica oleracea var. capitata* L., carrot, *Daucus carota var. sativa* L., and beet, *Beta vulgaris* L., are grown in several parts of Sri Lanka under different agroclimatic conditions. Their cultivation is concentrated predominantly in the highlands at elevations ranging from 750 to 1,900 m. At these elevations vegetative growth is normal, and fresh market vegetables true to type are obtained throughout the year. However, even during the coolest months of the year, field temperatures are not low enough to induce natural flowering. Consequently, the seed requirement for commercial cultivations has to be imported annually, utilizing scarce foreign exchange. If the seed could be produced locally, besides conserving foreign exchange, a new form of agricultural employment could be developed by diversifying the use of some land for the production of seed of exotic vegetables.

A pre-requisite for seed production in these vegetables is flowering. Miller[3] has reported that cabbage heads flower if they were pre-stored at 4.4°C for 30 to 60 days and then planted in the field. Carrots when pre-stored at 4.4 to 10.0°C for 15 to 60 days were shown to flower by Sakr and Thompson.[4] Beets were found to require higher storage temperatures ranging from 8 to 18°C for 2 to 3 months.[1,2,6,7] The experiments reported here were attempted to examine whether exotic vegetables would flower under field conditions in Sri Lanka when they were planted after they had been pre-stored in cold temperatures.

2. Materials and Methods

2.1. Experiment I

The experiment was conducted at the University Farm, Kundasale (elevation 450 m) from 24 December 1970 to 31 May 1971.

2.1.1. *Treatment of the plants for cold storage*

Beet : Whole plants of the cultivar Detroit Red were uprooted on 23 December 1970 keeping much of the root tip intact. The outer leaves were removed at the base of the petioles, leaving the small apical leaves and the apical bud intact. The plants so prepared were dipped in a solution of cupravit (50% copper oxychloride), at a dilution of 1 gm in 2.5 litres of water and air dried.

Cabbage : Plants of the cultivar KY cross were uprooted with their roots intact on 23 December 1970. After removing their outer leaves, the plants were dipped in the solution of cupravit, as for beet, and air-dried.

Carrot : Whole plants of the cultivar Cape Market were obtained from the wholesale market in Kandy. They were prepared for cold storage as for beet.

2.1.2. *Cold storage*

One lot of treated plants of beet, cabbage and carrot was packed in wooden crates lined with white polythene and stored in a cold room at a temperature of 0.5 to 1.0°C. Another lot of beet and carrot was packed in sealed white polythene bags and stored in a refrigerator at a temperature of 7.0 to 8.5°C. Sub-lots of the plants were removed from cold storage for field planting at intervals of 15 days, 30 days and 60 days.

2.1.3 *Field planting*

The three kinds of vegetables were planted in separate blocks in the same field. Each plot of cabbage had 10 plants replicated 3 times. Each plot of beet and carrot had 10 plants replicated 4 times. Planting was done the day they were removed from storage.

Cabbage was spaced 60 cm in the row and 90 cm between rows. Beet and carrot were spaced 15 cm in the row and 60 cm between rows. One week after the cabbage was planted, a cross shaped incision 2.5 cm deep was made in the head.

Recommended practices were adopted for pest and disease control and fertilization.[5] The plots were hand watered regularly.

2.2. Experiment II

This experiment was conducted with cabbage and carrot from 13 November 1971 to 15 April 1972 at the University Farm, Kundasale and the Government Research Station, Nuwara Eliya (elevation 1,850 m). Plants were stored for 40 days, 50 days

and 60 days at 0.5 to 1.5°C in a cold room. The method of pre-treatment and field planting was identical to experiment I. Plants of each treatment were removed from cold storage and one lot was planted in Kundasale the same day, while the other lot was planted in Nuwara Eliya the next day.

3. Results

3.1. Experiment I

The proportion of cold stored plants which survived and flowered after transplanting in the field is indicated in Table 1.

3.1.1. *Cabbage*

All the plants that were stored for 15 days and 60 days at 0.5 to 1.0°C survived in the field for 30 days. After that, the plants of the 15-day treatment showed a loss of 20% plants, whereas the 60-day treatment did not record a loss. Plant survival in the 30-day storage treatment was 46.66% ; this was maintained until the end of the trial.

Flowering was observed only in the 60-day treatment. Two plants flowered, one in 19 days and the other in 22 days after planting, to form small and poorly differentiated inflorescences.

3.1.2. *Beet*

Plant survival was highest among those stored for 15 days at 0.5 to 1.0°C. At this storage temperature, plant survival decreased when the period of storage was lengthened. All the plants which grew and survived for 30 days continued to do so until the end of the 90-day trial period.

The plants that were stored at 7.0 to 8.5°C for 15 days and 60 days showed a lesser survival ability when compared to those stored at the lower temperature regime. Plant mortality in the 60-day storage treatment was particularly high and only 17.5% survived the first month.

Flowering was not noticed in any of the treatments.

3.1.3. *Carrot*

Only 3.30% of the plants stored for 15 and 30 days at 0.5 to 1.0°C survived the first month after transplanting. None of the plants of the other treatments survived the first month. One plant of the 30-day low temperature treatment flowered in 43 days after planting.

3.1.4. *Rainfall*

Table 2 gives the total rainfall and its distribution from 1 January 1971 up to the end of March 1971. Rainfall was high during the weeks when the 15-day and 60-day treatments were planted on 8 January and 27 February respectively. Rainfall was low during the week the 30-day treatment was planted (23 January 1971) and it was followed by a dry spell of 3 weeks.

TABLE 1. Influence of cold storage of cabbage, beet and carrot on the survival and flowering of field grown plants.

	Storage temperature (°C)	Days in storage	Planting date 1971	%Survival — Mean of replicates			Plants flowering		Days to flower
				30 days	60 days	90 days	No.	%	
Cabbage	0.5 — 1.0	15	8 Jan.	100	80	80	0		
		30	23 Jan.	46.66	46.66	46.66	0		
		60	27 Feb.	100	100	100	2	6.22	19—22
Beet	0.5 — 1.0	15	8 Jan.	65	65	65	0		
		30	23 Jan.	60	60	60	0		
		60	27 Feb.	50	50	50	0		
	7.0 — 8.5	15	8 Jan.	42.5	42.5	42.5	0		
		30	23 Jan.	55	55	55	0		
		60	27 Feb.	17.5	17.5	17.5	0		
Carrot	0.5 — 1.0	15	8 Jan.	3.3	0	0	0		
		30	23 Jan.	3.3	0	0	1	1.66	43
		60*	27 Feb.	0	0	0	0		
	7.0 — 8.5	15*	8 Jan.	0	0	0	0		
		30**	23 Jan.	0	0	0	0		
		60***							

* Rotting in storage left only 10 plants per replicate for field planting.
** Rotting in storage left only 7 plants per replicate for field planting.
*** All the plants rotted in storage.

TABLE 2. Amount of rainfall and its distribution at Kundasale and Nuwara Eliya.

Week 1971	Rainfall	
	Total (mm)	No. of days
Jan. 1 — Jan. 7	3.2	4
Jan. 8 — Jan. 14	4.8	3
Jan. 15 — Jan. 21	—	—
Jan. 22 — Jan. 28	0.3	1
Jan. 29 — Feb. 4	—	—
Feb. 5 — Feb. 11	—	—
Feb. 12 — Feb. 18	—	—
Feb. 19 — Feb. 25	7.4	2
Feb. 26 — Mar. 4	9.5	3
Mar. 5 — Mar. 11	2.3	3
Mar. 12 — Mar. 18	—	—
Mar. 19 — Mar. 25	—	—

3.2. Experiment II

3.2.1. *Plant survival*

Cabbage plants that were cold-stored for 60 days survived better at both locations during the entire experimental period when compared with the other two storage treatments (Table 3). The best survival was recorded among plants that were stored for 60 days and then field planted at Nuwara Eliya. The rate of loss of field plants was highest during the first 30 days in all treatments at both locations. After 30 days, the rate of loss of plants was in general lower in Nuwara Eliya.

In general, carrot survived better than cabbage at both locations when they were pre-stored at the same temperature for comparable durations of storage (Table 4). As in cabbage, the rate of loss was high during the first 30 days ; but the losses were lower in carrot. With the exception of the 40-day storage treatment, the rate of loss of field plants after 30 days was lower in Nuwara Eliya.

3.2.2. *Flowering*

Cabbage plants of all three storage treatments flowered at both locations (Table 5). All the plants that survived in Nuwara Eliya flowered to give normal, well grown inflorescences. The flowering response at Kundasale was lower in all the treatments and the best response (57.14 %) was recorded for the 40-day storage treatment. The inflorescences so formed were poorly developed. Although the average number of days to flower was different for the 40-day, 50-day and 60-day treatments, in general, all healthy plants completed flowering within 7 weeks.

TABLE 3. Influence of cold storage and location of the planting on the survival of field planted cabbage.

Days in cold storage (0.5 — 1.5°C)	Location of planting	Planting date 1971/72	% Survival—Mean of replicates			% Rate of plant mortality		
			30 days	60 days	90 days	1—30 days	31—60 days	61—90 days
40	Kundasale	22 Dec.	46.66	33.33	6.66	53.34	13.33	26.67
40	Nuwara Eliya	23 Dec.	50	33.33	33.33	50	16.67	0
50	Kundasale	3 Jan.	56.66	23.33	0	43.34	33.33	23.33
50	Nuwara Eliya	4 Jan.	50	46.66	46.66	50	3.34	0
60	Kundasale	10 Jan.	66.66	43.33	9.99	33.34	23.33	33.34
60	Nuwara Eliya	11 Jan.	83.33	83.33	83.33	16.67	0	0

TABLE 4. Influence of cold storage and location of the planting on the survival of field planted carrot.

Days in cold storage (0.5 — 1.5°C)	Location of planting	Planting date 1971/72	% Survival—Mean of replicates			% Rate of plant mortality		
			30 days	60 days	90 days	1—30 days	31—60 days	61—90 days
40	Kundasale	22 Dec.	90	70	66.66	10	20	3.34
40	Nuwara Eliya	23 Dec.	83.33	81.66	41.66	16.67	1.67	40
50	Kundasale	3 Jan.	78.33	73.33	65	21.67	5	8.33
50	Nuwara Eliya	4 Jan.	86.66	85	85	13.34	1.66	0
60	Kundasale	10 Jan.	78.33	71.66	31.66	21.67	6.34	40
60	Nuwara Eliya	11 Jan.	81.66	76.66	76.66	18.34	5	0

TABLE 5. Influence of cold storage and location of the planting on the flowering of field planted cabbage and carrot.

Days in cold storage (0.5—1.5°C)	Location of planting	Planting date 1971/72	Cabbage					Carrot				
			Total flowered	% of total treated	% of total surviving	Flowering range (days)	Av. no. days to flower	Total flowered	% of total treated	% of total surviving	Flowering range (days)	Av. no. days to flower
40	Kundasale	22 Dec.	8	26.66	57.14	37-46	41.5	4	6.66	10	32-55	44.5
40	Nuwara Eliya	23 Dec.	10	33.33	100	49-126*	72.1*	0	0	0	—	—
50	Kundasale	3 Jan.	2	6.66	10.53	31	31	7	11.66	18	32-55	40.5
50	Nuwara Eliya	4 Jan.	14	46.66	100	37-52	43	1	1.66	1.92	61	61
60	Kundasale	10 Jan.	4	13.33	22.20	29-44	35.5	5	8.33	11.63	30-54	36
60	Nuwara Eliya	11 Jan.	25	83.33	100	30-49	37.8	1	1.66	2.17	51	51

*Two plants were retarded in growth and they flowered late. Excluding them, the range was 49-72 days and the average days to flower was 59 days.

TABLE 6. Amount of rainfall and its distribution at Kundasale and Nuwara Eliya.

Week 1971/72	Rainfall				Average temperature (oC)			
	Kundasale		Nuwara Eliya		Kundasale		Nuwara Eliya	
	Total (mm)	No. of rainy days	Total (mm)	No. of rainy days	Max.	Min.	Max.	Min.
Dec. 22 — Dec. 28	1.50	1	1.05	3	24.4	19.2	24.0	12.9
Dec. 29 — Jan. 4	0.43	1	0.70	2	29.3	21.1	25.9	12.5
Jan. 5 — Jan. 11	—	—	0.38	1	30.2	18.7	27.3	8.4
Jan. 12 — Jan. 18	—	—	0.28	1	35.8	18.0	28.9	9.5
Jan. 19 — Jan. 25	0.50	1	1.45	2	33.9	20.6	27.3	10.5
Jan. 26 — Feb. 1	2.82	3	6.50	3	34.6	20.6	26.1	10.3
Feb. 2 — Feb. 8	—	—	—	—	36.9	15.3	28.3	7.7
Feb. 9 — Feb. 15	—	—	—	—	37.9	18.1	30.3	8.0
Feb. 16 — Feb. 22	—	—	—	—	37.8	18.9	29.9	8.4
Feb. 23 — Feb. 29	—	—	—	—	36.4	19.5	28.0	9.4
For entire period	5.25	6	10.36	12	33.7	19.0	26.4	9.7
						Mean (26.4)		Mean (18.7)

The flowering response in carrot was better at Kundasale. At this location, all three storage treatments had flowering plants but the proportion of plants that flowered was low. The best response (11.66%) was recorded in the 50-day treatment. At Nuwara Eliya, the 40-day storage treatment did not induce flowering. In each of the 50-day and 60-day treatments, however, one plant flowered. As in cabbage, the plants that flowered did so within 7 weeks.

3.2.3. *Climatic Data*

Rainfall and temperature recordings at Kundasale and Nuwara Eliya from the first planting date (22 December 1971) up to the end of 7 weeks after the last date of planting (19 January 1972) are given in Table 6. Both the amount of rainfall and its distribution were poor in Kundasale when compared with Nuwara Eliya. Kundasale received 5.25 mm on 6 days during this period. Rainfall was recorded during 4 different weeks, while 6 weeks were dry. Nuwara Eliya had 10.36 mm of rain on 12 days during the same period. Rainfall was recorded during 6 different weeks, followed by 4 dry weeks.

The weekly variation of the maximum and minimum temperature within each of the two locations was small. Between locations, Nuwara Eliya, being at a higher elevation, had a lower average maximum and minimum temperature throughout the experimental period (Table 6). The mean temperature at Kundasale and at Nuwara Eliya for the entire period was 26.3°C and 18.6°C respectively.

4. Discussion

The survival of field transplants of exotic vegetables in Sri Lanka after they have been pre-stored at a cold temperature is essential for seed production. In this respect survival during the first 30 days was critical, as the first experiment has shown that almost all the plants that survived the first 30 days, survived until the end of the experimental period of 90 days. For beets, a longer storage period was less desirable. It was more so when the storage temperature was higher and was probably associated with the breakdown of the stored products, because many beets were observed to be less firm at the time of planting when the duration of storage was longer. The second experiment confirmed that the first month was a critical period, because mortality was highest for both cabbage (Table 3) and carrot (Table 4) during this period.

The first experiment suggested that the survival of cabbage at Kundasale was influenced by rainfall. The 15-day and 60-day treatments survived best, because it had rained soon after transplanting (Table 2). The 30-day treatment had a high mortality as it was associated with relatively low rainfall during the week after transplanting which was followed by a dry spell of 4 weeks. Even though the plants were irrigated, the bright, warm and sunny days which are common at Kundasale during a dry spell would not have been suitable for the quick establishment and high survival of new transplants of cabbage that had a large mass of succulent leaf tissue and no functional roots at transplanting.

The first experiment also suggested that the plants should be stored for more than 30 days at a low temperature to induce flowering in cabbage and carrot.

The second experiment was planned to narrow down the duration of cold storage that was necessary to induce flowering in cabbage and carrot and in addition to determine if a location with a lower mean temperature would have an influence on survival and flowering. Nuwara Eliya proved to be a better location for the field survival of cabbage, not only during the critical first month but also subsequent to it. The higher mortality of cabbage at Kundasale may have been due to the lower rainfall and its poor distribution when compared with Nuwara Eliya (Table 6). Perhaps lesser cloudiness and the higher intensity of radiation may have also encouraged the rapid desiccation and deterioration of plants at Kundasale. Although there was no difference in the field survival of carrot during the first month in the two locations, Nuwara Eliya was a better location for longer survival periods. Carrot was a hardier plant than cabbage at both locations. Rainfall would have influenced the better survival of carrot at Nuwara Eliya, as in the case of cabbage, but its effect was less.

A 40-day cold storage was sufficient to induce cabbage to flower. Even though some carrot plants that were stored for the same length of time flowered, a 50-day treatment was more effective (Table 5). Even though the floral primodia could be induced to form, the development of the inflorescence in the field was influenced by the field temperature. The lower temperatures at Nuwara Eliya would have assisted the elongation and development of a normal inflorescence in cabbage. At Kundasale, however, the lower proportion of flowering plants and the poor development of the inflorescences that emerged from the heads of cabbage plants would have been due to the higher mean temperatures. Even in plants which did not show an inflorescence, the induction of the floral primodia would have occurred in storage but the higher field temperature would have suppressed further development, even though the difference in the mean temperatures between the two locations was only 7.7°C. A similar relationship has been observed by Miller.[3] In his trial, cabbage plants that were grown in a 20°C greenhouse did not flower, whereas all the plants that grew in a 12.5°C greenhouse flowered. In carrot, however, the higher field temperature at Kundasale promoted the development of the inflorescence. But the majority of carrot plants did not show a visible inflorescence. Perhaps under field conditions in Sri Lanka, carrot may require a still higher field temperature for the development of its inflorescence. A location in the dry zone lowlands of Sri Lanka would be more suitable.

Acknowledgements

The writer wishes to thank the Farm Manager, University Farm, Kundasale and Mr. Cedric Vaz, Research Officer in Charge, Sita Eliya Experimental Station, for providing the necessary facilities and Mr. A. Samaratunge, Field Supervisor, University Farm, for recording the data. The writer gratefully acknowledges the research grant awarded by the National Science Council of Sri Lanka for this investigation.

References

1. CAROLUS, R. L. (1936) *Proc. Am. Soc. Hort. Sci.* **56**: 271-274.
2. CHROBOCZEK, E. (1934) *Mem. Cornell Univ. Agric. Exp. Stn* (154) : 32-33.
3. MILLER, J. C. (1929) *Bull. Cornell Univ. Agric. Exp. Stn* (488) : 10-16.
4. SAKR, EL SAYED & THOMPSON, H. C. (1942) *Proc. Am. Soc. Hort. Sci.* **41** : 343-346.
5. SCHOKMAN, D. (1966) *Vegetable growing : local and exotic varieties*, 29p. Colombo : Agriculture Department.
6. STOUT, N. (1946) *J. Agric. Res.* **72** : 49-68.
7. TOOLE, E. H., TOOLE, V. K., EMACK, E. E. & PARRISH, W. E. (1944) *Proc. Am. Soc. Hort. Sci.* **44** : 445-447.

J. Natn. Sci. Coun. Sri Lanka 1974 2 (1): 13-34.

The Magnetosphere and Geomagnetic Micropulsations with Special Reference to Micropulsation Studies in Sri Lanka

M. L. T. KANNANGARA

Department of Physics, University of Sri Lanka, Colombo Campus, Colombo, Sri Lanka.

(*Paper accepted : 22 March* 1974)

Abstract : This paper presents the physics of the magnetosphere in relation to geomagnetic micropulsations and summarises the significant results of the studies conducted and work in progress on geomagnetic micropulsations in Sri Lanka.

1. Introduction

About twenty five years ago, it was generally thought that interplanetary space was empty apart from sporadic gusts of wind composed of clouds of gas ejected from the sun and travelling outwards from the sun. Magnetic disturbances and auroral displays observed on the earth were explained in terms of these gusts of wind.

However, in the early 1950s, it came to be realised that the tails of comets could not be explained in terms of the pressure of light radiation from the sun as was the view then held. Calculations and certain experimental observations indicated that there must exist a continuous stream of ionised hydrogen atoms and electrons streaming out of the sun — a sort of solar wind. It was this wind blowing on the comets which formed their tail. It also became apparent that this solar wind must be continuously blowing on the earth system with its atmosphere and magnetic field. The actuality of the solar wind was directly verified in 1962 through observations from space probes. It was also observed that the earth's magnetic field was distorted in a most remarkable way by the solar wind (Figure 5) and that the earth's magnetic field occupied a clear-cut comet shaped region of space with the solar wind flowing round it like a high speed wind flowing round an obstacle. The comet shaped region occupied by the earth's magnetic field is called the *magnetosphere* (although it is not a sphere).

The magnetosphere is shaken by irregularities and gusts in the solar wind and this gives rise to the small fluctuations in the earth's magnetic field observed at ground stations. These fluctuations which often have a definite periodicity are called *geomagnetic micropulsations*.

2. The plasma state

Matter in space is largely in the state of an ionised gas, called the plasma state. The plasma state of matter is very different from the solid, liquid and gaseous states that we are more familiar with. An understanding of the plasma state, especially its behaviour in a magnetic field, is a prerequisite for understanding the magnetosphere.

One of the basic properties of an ionised gas is its tendency towards electrical neutrality.[11] If over a large volume, the number density of electrons deviates appreciably from the number density of positive ions, then comparatively large electrostatic forces result which yield a potential energy per particle that is very much larger than the mean random thermal kinetic energy. The principle of equipartition of energy does not allow such a deviation to exist and consequently any deviation from electrical neutrality would usually die down quickly.

A simple calculation helps to give a working definition of a plasma. Suppose the number density of electrons and positive ions in a gas are n_e and n_i respectively, and that each ion carries a charge e. The charge density in the gas would be $(n_i - n_e)e$. For simplicity let it be assumed that the charge distribution gives an electric field only in the x direction and that the associated electrical potential ϕ is given by Poisson's equation according to $\partial^2\phi/\partial x^2 = -(n_i - n_e)\, e/\varepsilon_0$ where the usual notation of SI units has been used. If the electric field (i.e. $-\partial\phi/\partial x$) is considered to be zero at a centre of symmetry at $x = 0$ and if we fix $\phi = 0$ at $x = 0$, then assuming that n_i and n_e do not vary with distance, the expression for ϕ is : $\phi = (n_i - n_e)\, ex^2/2\epsilon_0$. This means that if a particle with charge e moves in the x direction through a distance d from the centre its potential energy will change by an amount $\triangle W = |n_i - n_e|\, ed^2/2\varepsilon_0$. The value of d which makes $\triangle W = \frac{1}{2}kT$, where T is the temperature of the gas in degrees Kelvin and k is Boltzmann's constant would be $d = [kT/|n_i - n_e|\, e^2]^{\frac{1}{2}}$. When the relevant values of the constants are put in, one obtains $d = 6.9\,(T/|n_i - n_e|)^{\frac{1}{2}}$ cm where n_i and n_e are expressed in particles per cm^3. This value of d is called the "Debye shielding distance". Physically, d would be the distance over which a given deviation from electrical neutrality can be maintained. The principle of equipartition of energy will not allow such a deviation to exist over a greater distance without it dying down almost immediately. If d is much smaller than other characteristic lengths of the problem then the ionised gas is called a plasma.

3. Disturbances in a plasma in the presence of a magnetic field

From the definition of a plasma, it is clear that for phenomena varying slowly compared with the decay time of any charge density that may develop in the medium, it can be stipulated that the charge density is zero and hence also the rate of change of charge density. Then, since in basic electromagnetic theory the displacement current $\dot{D}$ comes from a rate of change of charge density, it follows

that in slowly varying phenomena in a plasma, $\dot{D}$ can be neglected. When considering the behaviour of a plasma in a magnetic field, if attention is limited to slow variations where $\dot{D}$ can be neglected, the subject is called *magnetohydrodynamics* or MHD. If fast variations are considered where $\dot{D}$ cannot be neglected, such as for radiowaves passing through the ionosphere, the subject is called *magneto-ionic theory*.

4. Elements of magnetohydrodynamics (MHD)

In MHD, the plasma behaves essentially like an electrically conducting fluid moving in the presence of a magnetic field. As a result of the motion, electric currents are induced in the fluid and these electric currents produce magnetic fields of their own which modify the ambient field. At the same time, electric charges travelling in a magnetic field are subjected to the Lorentz force, and this modifies the motion of the plasma. Thus one visualises constant interaction between field and motion. It would be clear that the interaction must become unimportant for very rapid field variations because of inertia, and hence, once again, it must be stressed that the subject of MHD is restricted to relatively slowly varying phenomena.

The fundamental equations governing MHD are :-

$$\frac{\partial \rho}{\partial t} + \text{div}\,(\rho v) = 0 \tag{1}$$

$$j = \sigma[E + \mu_0(v \wedge H)] \tag{2}$$

$$\text{Curl}\, H = j \tag{3}$$

$$\text{Curl}\, E = -\mu_0 \dot{H} \tag{4}$$

$$\text{div}\, H = 0 \tag{5}$$

$$\text{div}\, D = 0 \tag{6}$$

where ρ is the mass density of the medium, v the velocity of the medium, j the current density, σ the electrical conductivity and E, H and D are the field vectors which have their usual significance. Equation (1) is merely the law of conservation of mass. Equation (2) incorporates the Lorentz force on charged particles moving in a magnetic field. Equations (3) to (6) are Maxwell's equations neglecting the displacement current. Combining (2) and (4) and then substituting for j from (3) it is easy to show that :-

$$H = \text{Curl}\,(v \wedge H) + \frac{1}{\mu_0 \sigma} \nabla^2 H.$$

$\dot{H}$ is seen to be a sum of two parts. Let us consider them separately. If $\dot{H} = \text{Curl}\,(v \wedge H)$, then from (4) and (2) it follows that $j = 0$, which would mean that there is no relative motion between the conducting neutral medium and the

magnetic lines of force. In other words, the magnetic lines of force are frozen into the medium and carried with the medium. If L is a typical linear dimension of the medium a typical relaxation time for the transport of H lines by this process would be L/v. On the other hand, if we consider the second part separately and put $\dot{H} = (1/\mu_0\sigma)\nabla^2 H$ we have a typical diffusion equation with a diffusion coefficient $\alpha = 1/\mu_0\sigma$ which tells us that any applied magnetic field inhomogeneity will tend to become homogeneous by lines of force slipping through the medium with a time constant of the order of $L^2\mu_0\sigma$. In the general situation, both these effects are present; that is, lines of force are partially carried with the medium, but there is also some slipping of the lines of force through the medium.

There is an analogous situation in hydrodynamics in the viscous flow of fluids. We distinguish between streamline flow and turbulent flow. In streamline flow, the streamlines are stationary and the fluid slips through the streamlines easily. In turbulent motion, the streamlines tend to be carried with the fluid. A characteristic number called Reynolds number given by $R = Lv\rho\eta^{-1}$ determines when turbulent motion is important.

In MHD, there is a similar number which could be called the magnetic Reynolds number, given by $R_M = Lv\mu_0\sigma$ which determines whether transport of magnetic lines with the medium dominates or whether the slipping of lines through the medium dominates. If $R_M >> 1$, then transport dominates and the magnetic lines are effectively frozen into the medium ; if $R_M << 1$ then magnetic lines diffuse easily through the medium. The condition $R_M >> 1$ is very rare under laboratory conditions. However, in space, on a cosmic scale, L can be very large and the condition $R_M >> 1$ is easily satisfied, and in fact this is the situation that is usually met.

The freezing in of magnetic lines of force into a plasma introduces stresses within the plasma medium. Since the magnetic energy per unit volume in a magnetic field is $\mu_0 H^2/2$ (SI units), the principle of virtual work leads to the result that a magnetic field subjects the plasma to a tensional stress of μ_0/H^2 in the direction of the lines of force and simultaneously to a hydrostatic pressure of $\mu_0 H^2/2$ in addition to the normal gas kinetic pressure produced by the random thermal motion of the gas particles. In other words, one looks on the lines of magnetic force as taut-strings embedded in the plasma medium which subject the medium to a tension, whilst at the same time, they also cause an increase in the hydrostatic pressure of the medium. This picture is most helpful in understanding qualitatively the various types of low frequency mechanical waves that can travel through a plasma in a magnetic field.

5. Waves in a plasma in a uniform magnetic field

When parts of a plasma medium are displaced, restoring forces of two types can come into play. There is the normal type of pressure force involved through compressions and rarefactions of the medium. If this is the only type of restoring force involved, then we have pure *sonic waves*. On the other hand, any movement of the plasma medium at right angles to a line of magnetic force will carry the line of force with it and cause a magnetic restoring force to act. If the restoring forces operating are purely magnetic in origin, they are called *hydro-magnetic waves*. Often, both types of restoring force are involved and the resulting wave is then called a *magneto-sonic wave*.

If the movements of the medium are in the same direction as the lines of force, then there is no distortion of the magnetic field. Only gas kinetic pressure forces arising out of the compressions and rarefactions of the medium are involved and we have pure sonic waves propagated parallel to the lines of force with the usual velocity of sound, given by $C_s = (\gamma P/\rho)^{\frac{1}{2}}$ where γ, P and ρ have their usual significance. If the movements of the medium are at right angles to the lines of force, we can have two situations. In one, there are no pressure fluctuations involved, for example, when there is a twist of a bundle of lines of force. The restoring forces involved are then purely magnetic in origin and are due to lines of force acting like stretched strings. The velocity of these twist waves travelling along lines of force would by analogy with the velocity of transverse waves along a stretched string, be given by $V_A = (\mu_o H_o^2/\rho)^{\frac{1}{2}}$ where H_o is the strength of the ambient magnetic field. These are the pure hydromagnetic waves, which are also called Alfvén waves, after Alfvén who first visualised their existence. In the second situation, the movement of the medium at right angles to the lines of force causes pressure fluctuations in the medium caused both by gas kinetic compressions and rarefactions and by magnetic field strength variations produced by lines of force moving towards and away from each other. It can be shown easily that the velocity of such pure longitudinal magneto-sonic waves travelling at right angles to the lines of force is $(C_s^2+V_A^2)^{\frac{1}{2}}$. These are the simplest cases. When the direction of propagation is not along lines of force or at right angles, the situation is complicated but, as will be explained below, two basic modes could be distinguished.

Three basic vectors characterise the type of wave that is propagated through the plasma. They are H_o the ambient magnetic field vector ; k the propagation vector of the wave, which is in the direction of propagation of the wave ; and v the particle velocity in the medium associated with the wave. Now, any v can be resolved perpendicular to the plane (H_o , k) and parallel to it, and this enables us to recognise two basic modes : (a) v perpendicular to the plane (H_o, k) called the transverse mode and (b) v coplanar with (H_o, k). Suppose the angle between the direction of propagation of the wave front (i.e. k) and H_0 is ϕ. The phase velocity in case (a)

is $V = V_A \cos\phi$ and the wave is essentially a transverse Alfvén wave largely guided by the field lines but with its wave front inclined to the field lines. The phase velocity V in case (b) can be shown to be the roots of the equation $V^4 - V^2 (V_A^2 + C_S^2) + V_A^2 C_S^2 \cos^2\phi = 0$ which for a given ϕ gives two real roots for V^2 which correspond to a fast wave and a slower wave. In the magnetosphere, conditions are such that $V_A >> C_S$ and the faster mode corresponds to the magnetosonic wave described earlier, with $V = (V_A^2 + C_S^2)^{\frac{1}{2}}$ when $\phi = 90°$ and which degenerates into the pure Alfvén mode with $V = V_A$ when $\phi = 0$. For intermediate values of ϕ, V takes on values between these two extremes. This mode is only weakly guided by the field lines when $V_A >> C_S$ and is more or less isotropic. The slow wave corresponds to the pure sonic wave with phase velocity $V = C_S$ when $\phi = 0°$. In this mode, the phase velocity rapidly reduces to 0 as ϕ increases from 0 to 90°. Hence the slow wave is strongly guided by the field lines. Thus for a given ϕ, in general there would be three types of waves: (1) the transverse Alfvén mode (2) the fast magnetosonic mode and (3) the slow sonic mode. A polar diagram of the phase velocities of these three types of waves takes the form shown in Figure 1.

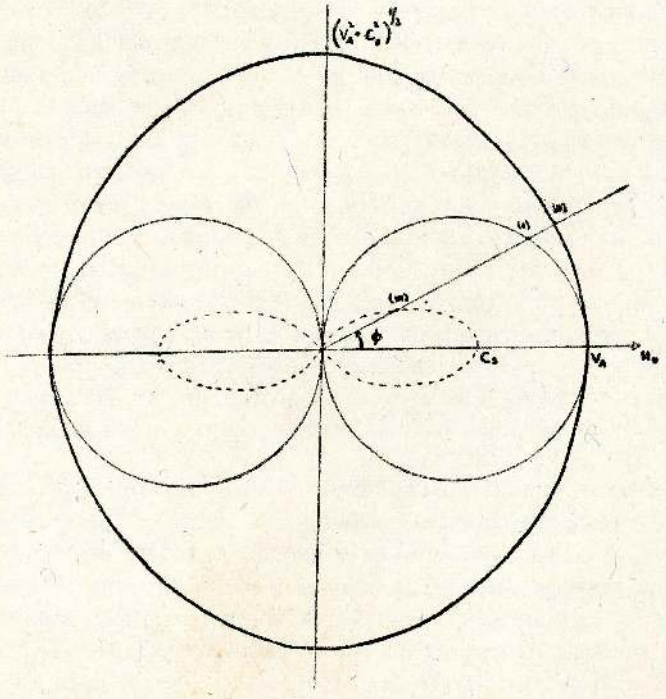


FIGURE 1. A polar diagram of the phase velocities of the three modes of propagation.

Type (3) waves are largely controlled by gas kinetic pressure fluctuations and would therefore be unimportant where ion collisions in the plasma are rare like in the magnetosphere. They are likely to become important only in the lower ionosphere. Hence in the main magnetosphere we need distinguish only two main types of waves : the transverse Alfvén mode, guided along field lines and the fast magnetosonic mode, which is more or less isotropic. In a uniform plasma which is uniformly magnetised, these two modes are independent. But non-uniformity causes coupling between the two modes and this gives rise to elliptically polarised waves, because in one mode v is perpendicular to the plane (H_o, k) and in the other mode it is parallel to this plane. This elliptical polarisation of the wave could be left handed or right handed with respect to the field lines. The heavy positive ions in the plasma would gyrate round the field lines in a left handed sense, thus qualitatively one would expect that the field lines would exert a bigger control on the mode with a left handed polarisation. Hence since it is the transverse Alfvén mode that is strongly controlled by the field lines, in the magnetosphere where the magnetic field is not uniform, the coupling of the two modes would make the Alfvén mode show left handed polarisation with respect to the field lines whereas the magneto-sonic mode which is only weakly controlled by the field lines would show signs of right handed polarisation.

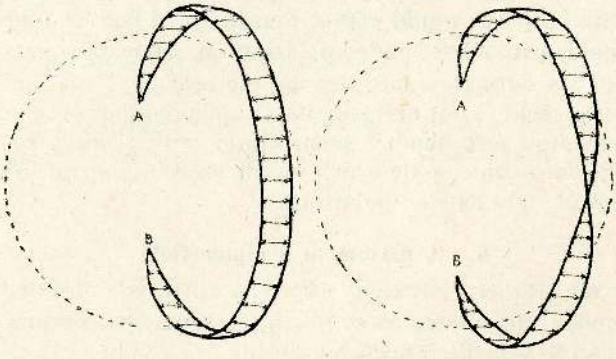
6. A plasma in a dipole field

Let us consider an idealised situation where the earth is associated with a dipole magnetic field and is surrounded by a spherically symmetric plasma. Certain basic types of waves can be visualised in such a plasma. Consider a magnetic shell, that is, a family of field lines dropping into a particular latitude and having all longitudes. In the earth model, it could be considered that the lines of force are effectively anchored to the base of the ionosphere. One can visualise standing waves set up on these field lines such that the particle velocities are always on the surface of the shell (Figure 2). If all the field lines of a shell move together, then these movements constitute a twisting of the entire shell. The waves will be of the Alfvén type and be confined to a torroid. Hence Alfvén type waves in a dipole field are often called torroidal waves. As in the case of a stretched sonometer wire, the period of the fundamental mode of these torroidal waves in a magnetic shell would be twice the travel time of an Alfvén wave moving along the field line from the conjugate points A and B of a field line. The period of the second harmonic would be half this period. These eigen periods would clearly depend on the length of the field line and the actual plasma density distribution along the line, and hence they would vary with the latitude of intersection of the shell with the earth's surface.

One can also visualise oscillations where the particle movements are at right angles to the surface of a shell (Figure 3). Here, the magnetic lines move in the meridian plane and move closer or away from lines in neighbouring shells, giving rise to magneto-sonic type waves. These are also called poloidal waves because the

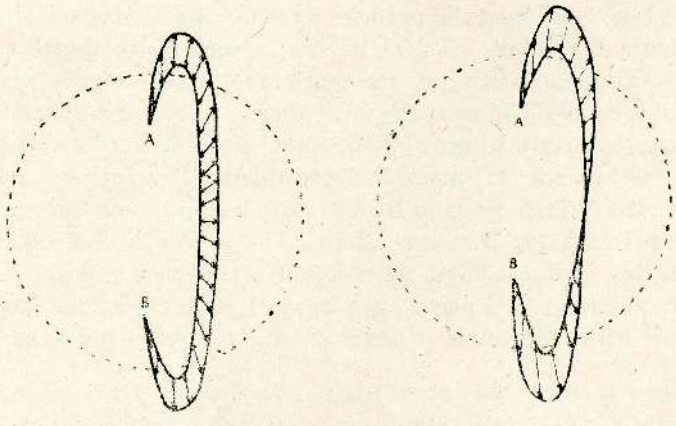
particle movements are essentially towards or away from a pole. These poloidal waves move across the field lines and spread to fill the entire plasma rather than being selectively guided by the field lines as in the torroidal mode. The fundamental period for standing waves of this type in the idealised earth model would be like that of a resonance tube closed at one end ; that is, four times the time taken for the magneto-sonic wave in the fast mode to travel from the ionosphere to the upper boundary of the plasma.

It will be appreciated that in the poloidal mode, the entire plasma resonates and the same period should be seen at all points. Oscillations in this mode should therefore not be latitude dependent.



Fundamental 2nd Harmonic
Torroidal Mode

FIGURE 2. Standing wave patterns in the torroidal mode.



Fundamental 2nd Harmonic
Poloidal Mode

FIGURE 3. Standing wave patterns in the poloidal mode.

These are the simplest modes. More complicated types of standing wave modes can be visualised where, for example, waves could be guided along field lines and yet be localised in longitude giving rise to what are called guided poloidal type oscillations. Obviously, very complex situations could arise. However, the simple picture presented above suffices to obtain a basic understanding of some of the oscillations that occur in the actual earth's magnetosphere.

7. The atmosphere above the earth's surface

Up to an altitude of about a 100 km, the atmosphere could be regarded as an unionised gas. From 100 km upwards, the atmosphere is appreciably ionised and we enter the region called the ionosphere. Collisions of ions with neutral molecules is frequent in the lower region of the ionosphere, but are less frequent in the upper regions. Beyond an altitude of about 600 km, the mean collision interval is larger than 600 s and the medium begins to behave like a plasma with geomagnetic field lines frozen into it and supporting hydromagnetic and magneto-sonic waves of the type described in the foregoing sections.

A uniform atmosphere settling under gravity does so with its mass density ρ decreasing exponentially with height. On the other hand, the earth's dipole field H_0 decreases with altitude as the inverse third power of the distance from the earth's centre. Under such circumstances, the Alfvén wave velocity $V_A = (\mu_0 H_0^2/\rho)^{\frac{1}{2}}$ would decrease with altitude.

In the actual atmosphere, however, there are two regions where ρ decreases much more rapidly than exponentially, causing V_A to increase with altitude. The first of these regions is between an altitude of 1,500 km and 3,000 km. In this region there is a very rapid decrease in ρ because the proportion of heavy ions compared with hydrogen decreases rapidly with height due to differential settling under gravity. At a height of about 3,000 km the plasma virtually consists entirely of hydrogen and there is again an exponential decrease in ρ, causing V_A to decrease with altitude again.

The second region begins at an altitude of about 12,000 km, which is about 2 earth radii above the earth's surface and extends up to an altitude of about 5 earth radii above the earth's surface. In this region, collisions are so rare that ions spiralling round lines of force and mirroring between conjugate points begin to build up the great radiation belts called the Van Allen radiation belts. As these particles spiral and mirror along lines of force, they also drift laterally because the earth's magnetic field decreases with altitude. This gives rise to an effective " ring current" which flows round the earth. The centre of gravity of this ring current is at an altitude of about 20,000 km which is about 3 earth radii above the surface of the earth. By Lenz's law, this ring current flows in a direction which would produce a magnetic field which opposes the cause that gave rise to it, namely the

decrease in H_0 with altitude. Hence, the magnetic field of the ring current would decrease the earth's field within it and enhance the earth's field outside it. The total pressure in the plasma is, as was shown earlier, $P+\mu_0 H_0^2/2$. This means that for pressure balance, an increase in H_0 can occur only at the expense of P and hence of ρ the density of the plasma. Thus, as one crosses the region of the radiation belts there is a sudden drop in ρ. This boundary region is called the *plasmapause*. Typically, the density within the plasmapause is some 20 times higher than the density outside. Hence there is an increase in the Alfvén wave velocity V_A with altitude in this region. The region within the plasmapause is sometimes called the plasmasphere, and the plasmapause marks the outerboundary of the relatively dense plasma which rotates with the earth.

The Alfvén wave velocity V_A varies with altitude roughly as indicated in Figure 4.

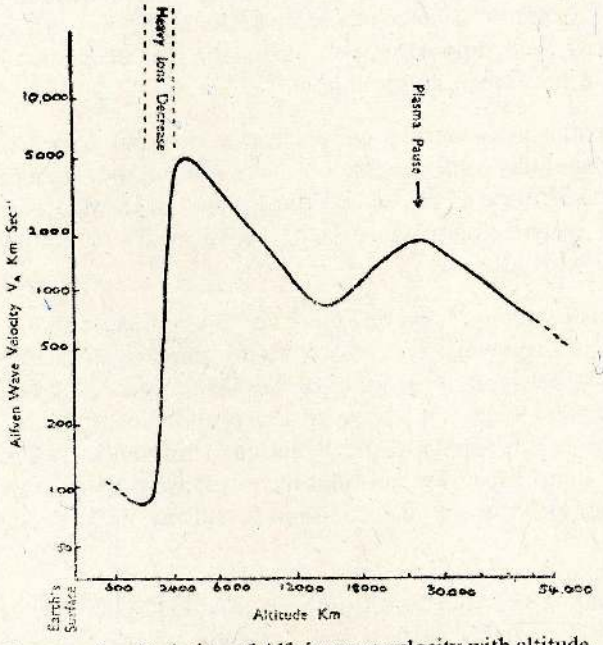


FIGURE 4. Variation of Alfvén wave velocity with altitude.

8. The actual magnetic field of the earth

The dipole magnetic field of the earth has an internal origin. It is distorted by three main external sources which are : (1) ionospheric currents, (2) ring currents, and (3) the solar wind.

At the earth's surface, ionospheric currents are much closer than the other disturbing sources, and variations in the earth's magnetic field detected at the earth's surface are ultimately due to ionospheric currents. Outside the ionosphere

in the region of the plasmapause, ring currents dominate. Beyond the plasmapause, rocket and satellite observations have revealed that the earth's field is distorted in a most remarkable way, due to the interaction of the solar wind with the earth's magnetosphere.

The solar wind is a stream of plasma which flows radially out of the sun through the solar system. Its existence was directly verified in 1962 by the Mariner 2 probe to Venus, and was shown to consist of protons and electrons. It has a quiescent bulk velocity of about 275 km/s near the earth's orbit. The sonic velocity in the solar wind is only about 20 km/s, which means that the solar wind is highly supersonic with a mach number of over 10. This supersonic wind hits the earth system.

As described earlier, the earth's magnetic field traps a plasma round it in the great radiation belts. If there was no solar wind, the earth's magnetic field would be largely dipolar, with a small distortion due to the ring currents of the radiation belts. By Lenz's Law, the supersonic highly conducting solar wind cannot penetrate into this earth plasma which contains the earth's magnetic field. It must flow round it. In other words, the solar wind sees the earth plasma as an obstacle in its path.

When a supersonic wind meets an obstacle, a shock pressure front must develop. Such a shock front does exist where the solar wind meets the magnetosphere. It was discovered by the IMP-1 satellite in 1963/64. The outer boundary of the magnetosphere is called the *magnetopause*. Satellite observations have revealed that there is a turbulent region between the shock front and the magnetopause to which the name *magnetosheath* has been given.

The total pressure in a plasma is $P + \mu_0 H^2/2$. Just outside the magnetopause, conditions are such that $P >> \mu_0 H^2/2$ and the magnetic field has little control over the mechanical motion of the solar wind. However, within the magnetopause $\mu_0 H^2/2 >> P$ and the motion of the plasma is completely controlled by the magnetic field.[12]

Satellite observations have also revealed a most extraordinary situation, behind the earth, in a direction away from the sun. It was found that the geomagnetic field stretches to form a long comet-like tail which extends well beyond the orbit of the moon.[8] The existence of the tail indicates that the solar wind catches geomagnetic lines of force at the magnetopause and blows them out behind the earth. This stretching of the lines would be resisted by the tensional stress $\mu_0 H^2$ in them. In the tail, the field is directed towards the sun in the northern half and away from the sun in the southern half. It has also been found that there is a well defined neutral sheet between the two halves, where as expected from the requirements of the $P + \mu_0 H^2/2$ pressure balance, the plasma density is relatively large.

A schematic drawing of the magnetosphere is shown in Figure 5.

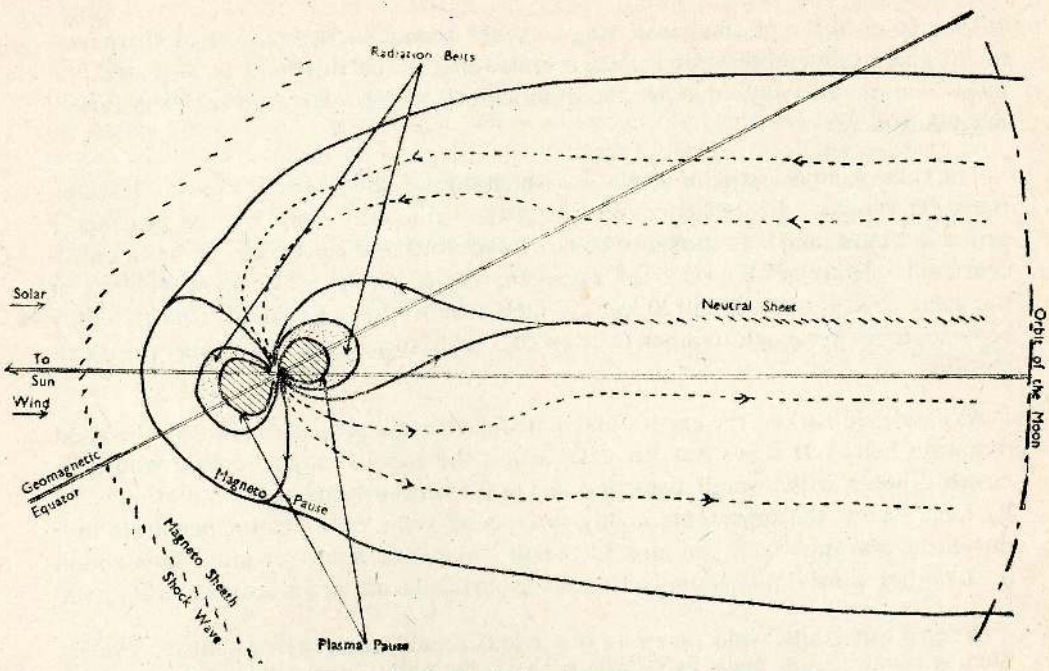


FIGURE 5. A schematic drawing of the magnetosphere.

9. Hydromagnetic waves in the magnetosphere

Observations from interplanetary space probes and satellites have revealed that there are variations in the solar wind velocity and particle density. These variations must give rise to fluctuations in pressure at the magnetopause. Also, just as much as waves are generated on the surface of a sheet of water when a wind plays on it, due to a process arising out of a phenomenon called the Kelvin-Helmholtz instability, there is an analogous instability at the magnetopause due to the solar wind flowing round it, which should generate surface hydromagnetic waves at the magnetopause. Processes such as these cause the magnetosphere to vibrate like a jelly. Complicated modes of standing waves can be set up, and these are only being gradually understood. After about ten years of research, a basic understanding is emerging although a lot more work remains to be done. This article presents only a qualitative description of some of the basic modes that could occur.

Let us first consider the surface waves generated on the magnetopause by the solar wind playing on it. From the stagnation point at the nose of the magnetosphere, the solar wind branches out towards the dawn and dusk meridians. Due to the earth's orbital velocity relative to the radial solar wind, the axis of symmetry of the magnetosphere is on an average tilted about 10 to 25° from the earth–sun line (Figure 6).[9]

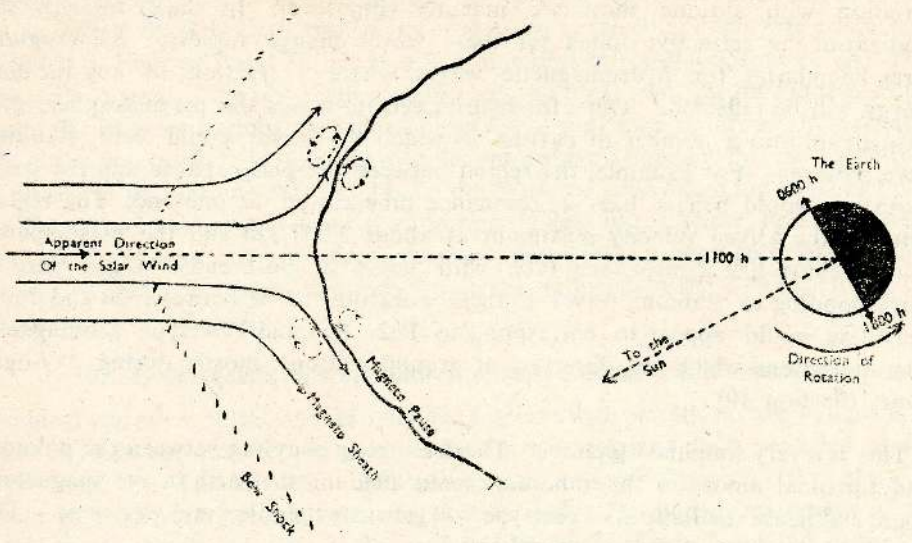


FIGURE 6. The solar wind playing on the surface of the magnetosphere.

The turbulent magnetic field in the magnetosphere carried by the solar wind, is preferentially directed towards the dawn and dusk meridians. Surface waves on the magnetopause will, like waves on the sea, have an approximately elliptical motion, the rotation being in the opposite sense on the dawn side and the dusk side from the stagnation point. The earth's magnetic field lines, which would come out of the plane of the paper in the diagram of Figure 6, being frozen into the magnetospheric plasma, will participate in this elliptical motion of the plasma on the magnetopause, and hence generate elliptically polarised Alfvén waves along the field lines which are near the magnetopause. Looking in the direction of the magnetic lines, the polarisation would be left handed on the dawn side and right handed on the dusk side, with the line of change being at about the 11.00 h meridian. Observations made from the Explorer 33 satellite in 1970 support this picture. The field lines excited by this mechanism are on the outermost magnetic shell. The eigen period of the fundamental mode for standing waves (Figure 2) on these lines is about 10 to 15 min. These field lines dip into the earth at high latitudes and large, long period oscillations of the earth's magnetic field (called Pc 5 type micropulsations) observed at ground stations in high latitudes (68 to 70°) would appear to correspond to these oscillations.

The variations in pressure on the magnetopause caused by variations in velocity and density in the solar wind, should generate poloidal oscillations especially in the central regions of the sunlit magnetopause. The Alfvén wave velocity

variation with altitude show two maxima (Figure 4). In these regions, the gradient of the refractive index for these waves change rapidly. Such regions form boundaries for hydromagnetic waves, where a fraction of any incident energy will be reflected. Thus, for hydromagnetic waves the magnetosphere gets divided up into a number of cavities in which the waves could form standing wave patterns. For example, the region between the plasmapause and the magnetopause would behave like a resonance tube closed at one end. The region between the Alfvén velocity maximum at about 2,000 km and the plasmapause would behave like a resonance tube with nodes at both ends. Eigen periods corresponding to standing waves in these work out to be between 20 and 150 s and these would appear to correspond to Pc2, Pc3 and Pc4 type geomagnetic micropulsations which are observed at ground stations, mostly during day-light hours (Section 10).

This is a very simplified picture. There is strong coupling between the poloidal and torroidal modes in the inhomogeneous field of the earth in the magnetosphere and hence oscillations of one type will generate the other and *vice versa*. The actual situation is therefore complicated.

At night-time, especially towards midnight, sharp pulses of damped oscillations called Pi2 type micropulsations are observed in the geomagnetic field. These oscillations would appear to be connected with an impulsive type of phenomenon in the geomagnetic tail. A possibility that has been suggested is the reconnection of oppositely directed field lines across the neutral sheet. This forms a situation like that of a stretched catapult. The reconnected lines snap back like the strings of a catapult and in doing so catapult the plasma in the neutral sheet between them towards the earth giving rise to, amongst other things, an impulsive stimulation of the resonating cavities on the night side of the magnetosphere.

So far, only standing waves in the magnetosphere have been considered. These have slow periods and wavelengths of the order of the linear dimensions of the magnetosphere. When the wavelength of hydromagnetic waves is very small compared with magnetospheric dimensions there is the possibility of travelling hydromagnetic waves in the magnetosphere. These waves have periodicities of the order of 0.2 to 5 s. Such periodicities are detected in geomagnetic micropulsations and are called Pc1 type oscillations. It is interesting to note that in the outer magnetosphere the magnetic field strengths are such that the period of gyration of protons in these fields is also of the same order of magnitude as these oscillations. One can then imagine a resonance interaction between Alfvén waves with these periods travelling along the outermost field lines and showing a left handed elliptical polarisation, as explained earlier, and the gyrating protons. By a process called "Landau Damping" the hydromagnetic wave can lose energy to the resonant particles, and the reverse can also happen through a mechanism called the cyclotron

resonance mechanism. These processes could cause pulses of oscillations to run up and down the field lines after being repeatedly reflected at conjugate points (e.g. A and B in Figures 2 and 3), where a field line dips into the ionosphere. At each reflection, a part of the wave will get reflected and a part will get transmitted to the earth. Pc1 micropulsations are indeed observed at conjugate points at high latitudes where the outermost field lines dip into the ionosphere. Further, the repetitive time of pulses of oscillations corresponds to the expected time taken for an Alfvén type oscillation to travel up and down the appropriate field line. These Pc1 oscillations are also observed at other latitudes because a part of the energy gets conducted to these latitudes by means of current patterns induced in the ionosphere by the oscillation of the field lines.

10. Geomagnetic micropulsations observed at the earth's surface

Geomagnetic micropulsations are small fluctuations with periods between about 0.2 s and 600 s that are observed to occur in the earth's magnetic field recorded at the earth's surface. The amplitude of these fluctuations vary from a fraction of a γ to about 10 γ where a γ is equivalent to 10^{-5} oersted. The quiescent strength of the earth's magnetic field in equatorial regions like Sri Lanka is about 0.4 oersted or 40,000 γ. Hence it will be realised that these fluctuations are relatively small and that special sensitive techniques have to be used to record them.

These geomagnetic micropulsations are sometimes continuous in character and are called Pc type oscillations (P for pulsation, c for continuous). Pc type oscillations occur largely during day-time. Night-time micropulsations are, more often than not, impulsive in character and are like heavily damped oscillations. Such oscillations are called P_i type oscillations (i for impulsive). By international agreement, geomagnetic micropulsations are classified according to period as follows :-

Type of oscillation	Period range seconds
Pc1	0.2—5
Pc2	5—10
Pc3	10—45
Pc4	45—150
Pc5	150—600
Pi1	1—40
Pi2	40—150

The need for electrical neutrality in a plasma requires that, for slowly varying phenomena like geomagnetic micropulsations, the electrical charge density in a plasma be taken as zero. As pointed out earlier, this also requires that the displacement current $\dot{D}$ in the plasma be taken as zero, and the fundamental equations

governing plasma oscillations would be as stated in equations (1) to (6) in Section 4. It will be seen from equation (3) of Section 4 that the magnetic field variations in a plasma corresponding to the periods considered here must originate through fluctuating current densities only, and not through changes in the displacement current $\dot{D}$ as well, as is the case in the usual electromagnetic wave theory.

In the magnetospheric plasma, four main regions where current densities are likely to be generated can be identified. They are : (1) the magnetopause where surface currents would be induced due to interaction with the solar wind, (2) the plasmapause which is the region of the ring current produced by the great radiation belts, (3) the neutral sheet in the geomagnetic tail of the magnetosphere and (4) the ionosphere. The magnetic effects of these currents would drop off roughly in inverse proportion to the distance from the current sheet. The nearest current sheet to the earth's surface is the ionosphere which is at least a few hundred times nearer than the next nearest current sheet at the plasmapause.

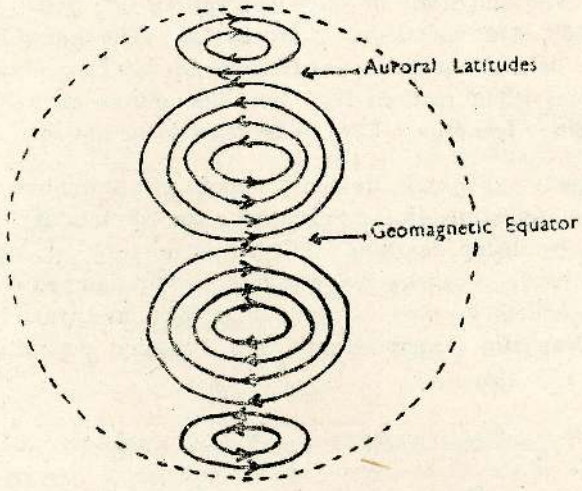


FIGURE 7. Ionospheric current pattern giving rise to geomagnetic micropulsations.

Hydromagnetic waves in the magnetosphere impinging on the ionosphere must produce fluctuating current systems in the ionosphere like the wall currents in a wave guide. In equatorial regions and mid-latitudes at least, it should be the induction effects of these current systems in the ionosphere, together with the image currents they induce in the earth, that are observed as geomagnetic micropulsations. It can be concluded, therefore, that hydromagnetic waves with the same periodicities as observed in geomagnetic micropulsations must be present in the magnetosphere. It is, however, not easy to infer the nature of the hydromagnetic waves incident on the ionosphere from a study of the geomagnetic micropulsations recorded at the earth's surface. Various attempts have been made with

model ionospheres to evaluate transmission coefficients for hydromagnetic waves falling on them. These calculations are, as yet, not very convincing. Furthermore, the induced earth currents could vary drastically depending on the locality where observations are being made, and these earth currents could seriously distort the observed micropulsations, especially their polarisation. These factors indicate that geomagnetic micropulsations must be interpreted with caution.

By analysing the distribution pattern of simultaneous signals from recorders distributed at various points on the earth's surface, Jacobs and Sinno[4] suggested as early as 1960 that an ionospheric current pattern of the type indicated in Figure 7 seemed to be the agency responsible for at least the long period micropulsations observed at the earth's surface.

The current pattern induced in the ionosphere due to the tidal motion of the atmosphere, called the Sq. current pattern is also similar.[5] This sort of pattern, where there are big loops of current on either side of the geomagnetic equator which join up over the equator to produce a sort of equatorial jet current seems to be a natural pattern for the ionosphere. In the case of the Sq. current pattern caused by tidal motion, the current jet over the equator is very marked at midday longitudes, and is called the equatorial electrojet.

11. Research on geomagnetic micropulsations in Sri Lanka

Geomagnetic micropulsations can be studied by measuring the small currents or electromotive forces induced by them in suitably designed coils, or by measuring the currents induced by them in the earth's crust near the surface (telluric currents).

Investigations on geomagnetic micropulsations using the first technique were initiated at the Physics Department of the University of Ceylon, Colombo in 1963 (on the author's suggestion) by P. C. B. Fernando and the author.[5] Measurements of telluric currents were initiated at the Vidyodaya University of Ceylon by P. C. B. Fernando and A. Perera in 1968.[3]

Experimental details are given in the relevant papers ; this paper briefly indicates the significant results of investigations conducted in Sri Lanka. When these investigations were begun in 1963, the magnetosphere was little understood. The solar wind had only been recently discovered and there was virtually no information on geomagnetic micropulsations from equatorial regions. Records from high and middle latitudes had indicated that the dominant period of micropulsations in high (auroral) latitudes was about 55 to 60 s and that this dominant period decreased as the latitude decreased.

Fernando and Kannangara[2] showed that the main characteristics of Pc3 and Pc4 type micropulsations recorded in Colombo during the period 20 April to 23 May 1964 were :-

(i) The total micropulsation activity has a mean diurnal variation that builds up to a maximum just before local noon. There also occurs a slight enhancement of activity around local midnight.

(ii) The total activity shows a strong positive correlation with Kp (a world wide magnetic disturbance index).

(iii) The observed activity in the Pc3 and Pc4 band micropulsations is mainly confined to periods lying between 30 and 60 s with peak activities at (38 ± 5) s and (60 ± 5) s.

(iv) The 60 s peak is the dominant one and is highly stable, occurring both in day and night signals. It is also composed of the larger amplitude signals.

(v) The 38 s peak is constituted from smaller amplitude signals and is enhanced under day-time conditions and particularly under magnetic storm conditions.

(vi) The midnight pulsations form a rather broad spectrum with no pronounced peaks at 38 or 60 s but a broad peak at (55 ± 10) s. These are found to consist mainly of damped oscillations of the Pi type.

(vii) Apart from perhaps some sporadic bursts of activity, there is no indication of a general resonance at a period of the order of 20 s as had been reported by many mid-latitude stations.

The dominant period and some other characteristics of the micropulsations recorded by Fernando and Kannangara were in fact more similar to the micropulsations found in auroral latitudes rather than in middle latitudes. This observation lent support to the view put forward by Jacobs and Sinno described previously (Section 10). The ionospheric current loop which flows over equatorial regions would continue round to auroral latitudes and hence similar micropulsations should be seen both at equatorial and auroral latitudes.

Kannangara and Fernando,[7] made a detailed analysis of night-time Pi2 micropulsations from continuous records of micropulsations taken over a whole year in Colombo from 17 October 1964 to 16 October 1965. The main characteristics of these night-time Pi2 pulsations were :-

(i) Pi2 events are most prominent, especially about midnight, during the equinoxes.

(ii) The rate of occurrence of Pi2 events increases almost linearly with Kp up to a Kp level of at least 5.

(iii) The dominant periodicity of Pi2 events shows a definite Kp dependence, the median shifting smoothly from a value of about 100 s at the Kp = 0 level to about 45 s at the Kp = 5 level.

(iv) Pi2 oscillations tend to have longer periods when they occur at, or immediately before, midnight and to have shorter periods when they occur at predawn.

Perhaps the most interesting result of this analysis was the spectacular increase shown in Pi2 activity at the equinoxes. It was pointed out that the neutral sheet of the magnetosphere points directly at the earth only at the equinoxes. This can be deduced easily if it is realised that the schematic picture of the magnetosphere shown in Figure 5 corresponds to summer in the northern hemisphere. A convincing mechanism which would cause an enhanced Pi2 activity at the equinoxes has not yet been worked out.

Polarisation studies of micropulsations were made by the author in Colombo from records taken during the period April to December 1971.[6] The following polarisation characteristics were observed:-

(i) The magnetic vector of the micropulsations lies almost entirely in the plane of the magnetic meridian.

(ii) The magnetic vector is almost horizontal for signals with periods <60 s at all times.

(iii) As the period increases, the magnetic vector becomes more inclined to the horizontal. This increase in inclination as the period increases is very gradual at night-time and $\triangle Z/\triangle H$ is still ~ 0.2 at a period of 600 s. During the day-time, $\triangle Z/\triangle H$ increases much more as the period increases and has a value of about 0.6 at a period of 600 s. ($\triangle Z$ = vertical compodent, $\triangle H$ = horizontal component).

(iv) The building of $\triangle Z/\triangle H$ for long period signals during day-time seems to follow the build-up and decay of the E region of ionisation in the ionosphere.

(v) The equatorial electrojet current does not have a first-order effect on the polarisation of micropulsations.

(vi) The polarisation characteristics do not show a first-order seasonal dependence.

(vii) In a periodic signal with both H and Z components, when H increases in a S→N sense, Z increases in a vertically downward sense and *vice versa*.

The author has shown that all these polarisation characteristics observed in Colombo could be explained in terms of a current pattern in the ionosphere of the type shown in Figure 7 as being the agency responsible for the micropulsations observed at the earth's surface. For equatorial stations like Colombo, the ionospheric currents inducing the micropulsations would be currents flowing in the E ⇌ W direction over the region of the geomagnetic equator. During day-time these currents would be in the E region and at night-time when the E region disappears the current would rise to the F region. The magnetic disturbance recorded at the earth's surface would be the resultant magnetic effect of this ionospheric current and its image current in the conducting earth. If the earth was a perfect conductor, the image current would be a current of the same strength as the ionospheric current and situated as far below the surface of the earth as the ionospheric current is above it. However, the earth is not a perfect conductor, and from considerations of skin depth of penetration of electromagnetc signals into a surface with finite conductivity, it was deduced that the effective image current would be situated deeper in the earth than the mirror image position, and also the depth of the image in the earth would increase as the periodic time of the signal increases. A surface observer then becomes asymmetrically placed with respect to the ionospheric current and its image, and hence depending on the degree of asymmetry, a Z component must appear in the micropulsation signal when the observing station is not directly on the geomagnetic equator. The bigger the asymmetry, the bigger would be the Z component. Thus, the increase in $\triangle Z/\triangle H$ as the period increases and the reason for the increase being not so marked at night-time is understandable, because a shift of the ionospheric current to the much higher altitudes of the F region would reduce the asymmetry. Hence a very satisfactory explanation of the polarisation characteristics observed in Colombo could possibly be made. Incidentaly, the sense of polarisation of the signals indicated that the ionospheric current sheet was north of Colombo, and indeed the geomagnetic equator passes through Sri Lanka in the region of Vavuniya, which is about 150 miles north of Colombo.

An obvious check on these results would be to make polarisation studies north of the geomagnetic equator and on it. This is being done presently by K. Kunaratnam of the University of Sri Lanka, Colombo Campus. He is taking recordings in Jaffna and Vavuniya; the former is located north of the geomagnetic equator, and the latter is more or less on the geomagnetic equator. Preliminary results reported by Kunaratnam give striking confirmation of the interpretation given above. The sense of polarisation of the signals recorded in Jaffna is opposite to that of the signals recorded in Colombo, and the signals recorded in Vavuniya have no vertical component at all. Mathematical support for the model used by the author has been given by Park.[10]

It was not possible to record the fast Pc 1 micropulsations at the Colombo Campus. However, the telluric current recorder set up at the Vidyodaya University, Nugegoda was capable of recording these signals. Fernando[1] presented an

analysis of 117 Pc 1 events recorded at Nugegoda. Pc1 oscillations often appear as short emissions which repeat themselves at regular intervals, giving the appearance of a string of pearls on the recorder chart. Hence these events are often called pe arl events. The main features of the pearl events observed by Fernando were:

(i) Pearls occur in the day-time with peak occurrences between 1030 and 1100, 1230 and 1300 and 1530 and 1630 h local time.

(ii) The most probable: (a) duration of a pearl event is about 10 min, (b) number of emissions (bursts) per event is between 5 and 10, (c) duration of an emission is between 40 and 50 s, (d) time interval between two successive events is 10 min to 1h.

(iii) During the day-light hours the mean wave period t_m remains substantially constant while the mean repetition period between successive emissions T_m reaches a minimum at 1230 local time.

(iv) The most probable mean wave period t_m is between 1.0 and 1.5 s.

(v) The most probable T_m/t_m ratio is 40 ± 10 for all events, 50 ± 10 for events with $t_m < 2$ s and 35 ± 10 for events with $t_m \geq 2$ s. The T_m/t_m ratio of noon signals is almost half that of the afternoon and morning signals.

Fernando interprets this last observation of the halving of T_m (t_m is substantially constant) for noon signals as being due to the feeding in of energy from Pc1 signals to both the northern and southern loops of the equatorial electrojet current system in the ionosphere through conjugate points in the northern and southern zones.

Normally, the repetition period T_m between two successive Pc1 emissions would correspond to the time taken for a packet of hydromagnetic waves to travel along the outer field lines of the magnetosphere from one conjugate point to the other and back again. When the equatorial electroject current system which is created by the tidal motion of the ionosphere is fully developed, Fernando considers that at each "bounce" of the hydromagnetic wave packet at a conjugate point in the northern hemisphere and in the southern hemisphere respectively, energy is fed into the appropriate current loop in the ionosphere and gets carried into the equatorial regions. Hence in equatorial regions T_m becomes halved at noon when the equatorial electroject current system is fully developed. The Vidyodaya results thus appear to be another pointer to the important role played by ionospheric current systems in the generation and propagation of geomagnetic micropulsations of all periods from Pc1 pulsations to Pc5 pulsations observed at the earth's surface.

This account reveals that with very modest equipment and very meagre resources, Sri Lanka has made a small but significant contribution to this fascinating field of research.

References :

1. FERNANDO, P. C. B. (1971) *Proc. Ceylon Ass. Advmt. Sci.* **27** (1): 95-96.
2. FERNANDO, P. C. B & KANNANGARA, M. L. T. (1966) *J. Geophys. Res.* (*Space Phys.*) **71** : 5149 - 5155.
3. FERNANDO, P. C. B. & PERERA, A. (1968) *Proc. Ceylon Ass. Advmt Sci.* **24** (1) : 58.
4. JACOBS, J. A. & SINNO, K. (1960) *Univ. Br. Colomb. Geophys. Lab. Sci.Rep.* (2) : 1-31.
5. KANNANGARA, M. L. T. (1964) *Proc. Ceylon Ass. Advmt Sci.* **20** (2) :121-142.
6. KANNANGARA, M. L. T. (1972) *J. Geophys. Res.* (*Space Phys.*) **77** : 6161-6167.
7. KANNANGARA, M. L. T. & FERNANDO, P. C. B. (1969) *J.Geophys. Res.* (*Space Phys.*) **74** : 844 - 852.
8. NESS, N. F. (1969) *Rev. Geophys.* **7** : 97-127.
9. ORR, D. (1973) *J.Atmos. Terr. Phys.* 35 : 1-30.
10. PARK, D. (1972) *J. Geophys. Res.* (*Space Phys.*) 77 : 6278.
11. SPITZER, L. (1956) *Physics of fully ionised gases*, p. 16. New York: Interscience.
12. SPREITER, J. R. & ALKENESE, A. Y. (1969) *Rev. Geophys.* **7** : 11-50.

J. Natn. Sci. Coun. Sri Lanka 1974 2 (1): 35-49.

Essential Oils

II. Infra-Red Spectroscopy in the Analysis of the Volatile Oils of Cinnamon†

R. O. B. WIJESEKERA AND KANTHI H. FONSEKA *

Section of Natural Products,
Ceylon Institute of Scientific and Industrial Research (CISIR), P. O. Box 787, Colombo 7, Sri Lanka.

(*Paper accepted : 17 April 1974*)

Abstract : The chemical composition of cinnamon leaf, stem bark and root bark oils has been examined recently using GLC methods. Infra-red spectroscopy has been used in essential oil studies, mainly as a qualitative technique. In this study, infra-red spectroscopy has been employed to quantitatively estimate the main constituents of the cinnamon oils. These include eugenol, cinnamaldehyde, acetyl eugenol, cinnamyl acetate and benzyl benzoate in leaf oil ; cinnamaldehyde, eugenol and cinnamyl acetate in stem bark oil ; camphor, 1:8 cineole and cinnamaldehyde in root bark oil. The results obtained are in close agreement with those obtained by GLC.

1. Introduction

Infra-red spectroscopy has been widely used in analytical studies on essential oils,[2–5] together with other modern instrumental methods such as GLC, NMR and Mass Spectrometry. Farnov[5] has discussed the relative merits of the infra-red spectroscopic techniques and chromatographic methods in the analysis of essential oils. He has attempted to identify the spectra of many of the essential oils in terms of the features of the spectra of the major constituents in each of them. For example, the infra-red spectra of lavender oil, lavendin oil and spike oil show striking similarity. The two former oils contain mainly linalool and linalyl acetate and their spectra display the features of the spectra of these individual compounds. Spike oil, on the other hand, contains substantial quantities of 1 : 8 cineole and camphor, in addition to linalool, and its spectrum therefore displays much of their characteristics. Carroll and Price[3] have used infra-red spectroscopy as a routine analytical method for analysis of essential oils ; they have used peak intensity measurements in the analysis of citronella oil. Das Gupta and Bhattacharya[4] have successfully used infra-red spectroscopy as a method of distinguishing between the two geraniols obtained from Java citronella oil and Indian palmarosa oil. Our experience with Sri Lanka cinnamon oils is that the genuineness or otherwise of these oils could be readily revealed by a casual examination of their infra-red spectra.[16]

† This Journal, **1** (2) : 67-81 is now considered as Part I of this Series.

* This work will form part of a Ph.D. thesis requirement (University of Sri Lanka, Colombo Campus) of Kanthi H. Fonseka.

Qualitative and semi-quantitative analytical data based on the infra-red spectra of a great many essential oils have been compiled by Bellanato and Hidalgo.[2] Our studies on the Sri Lanka cinnamon oils have revealed several ambiguities and errors in the assignment of peaks in the spectra of these oils by these workers. Infra-red spectroscopy has hitherto been used successfully to supplement GLC methods in the study of essential oils.[12–15] However, its role has been primarily qualitative. We have successfully used infra-red spectra as a means of quantitatively determining the major constituents of the cinnamon oils. Our studies are being extended to other essential oils produced in Sri Lanka.

2. Experimental

2.1. Samples of oil

Samples of essential oils analysed were genuine oils obtained from reliable commercial sources in Sri Lanka ; some samples were distilled by us from authentic plant material gathered from the cinnamon growing areas in the southern part of the island; these samples were also used in a previous study[12] employing GLC methods.

2.2. Infra-red spectrophotometry

The apparatus used was a Perkin-Elmer model 700 double-beam spectrophotometer with sodium chloride optics. Spectra were recorded as smears or as solutions in chloroform (spectro grade) ; optimum dilutions and cell thicknesses were preselected. An equivalent cell containing chloroform placed in the path of the reference beam was employed to compensate for the absorptions due to the solvent. All solutions were made using Hamilton micro-syringes for measurement of the essential oils and components.

The validity of the Beer-Lambert Law for quantitative analysis was first established by plotting Absorbance at selected frequencies against Concentration, a linear relationship being obtained.[16]

2.3. Measurement of absorbance

Absorbance was measured by use of the 'baseline' technique.[9]

2.4. Assignment of absorbance peaks

The assignments of the peaks of the infra-red spectrum of an essential oil as being due to various individual constituents were made by comparison with the characteristic peak frequencies in the individual spectra of the pure constituents. The peak enhancements in the spectra of the essential oil caused by the addition of a small amount of a pure constituent helped to further indicate such peaks as being due to that particular constituent (Figure 1).

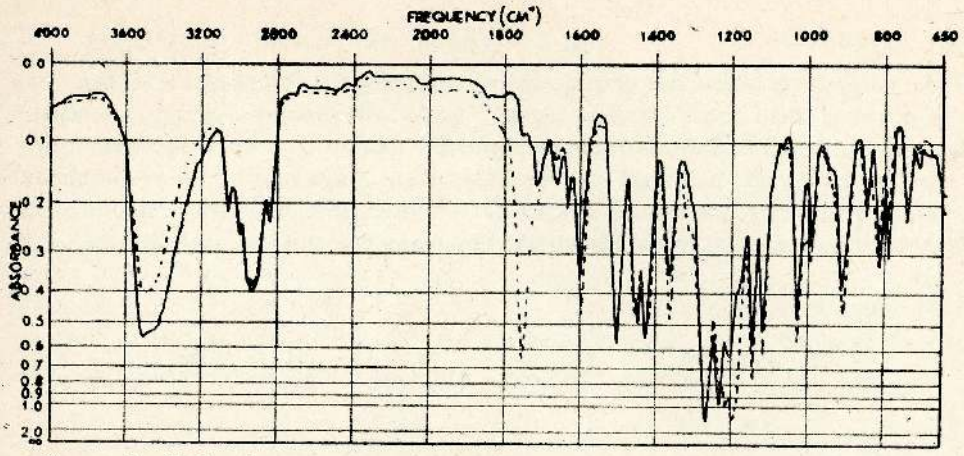


FIGURE 1. Peak enhancement caused by addition of acetyl eugenol to cinnamon leaf oil.
Continuous line — Cinnamon leaf oil.
Dotted line — Cinnamon leaf oil to which acetyl eugenol has been added.

2.5. Differential spectroscopy

The peak assignments were confirmed by differential spectroscopy.[10] Here, a small amount of the respective pure compounds was added, one at a time, to the solvent in the reference beam. This resulted in the peaks due to this constituent being reduced (Figure 2). If the quantity added was exactly equal to the amount present in the oil (where the peak is due solely to this compound), the complete disappearance of this peak was observed. Thus, after the estimations by the methods discussed in **2.6.** below were carried out, the accuracy of these estimates was checked by obtaining the differential spectrum.

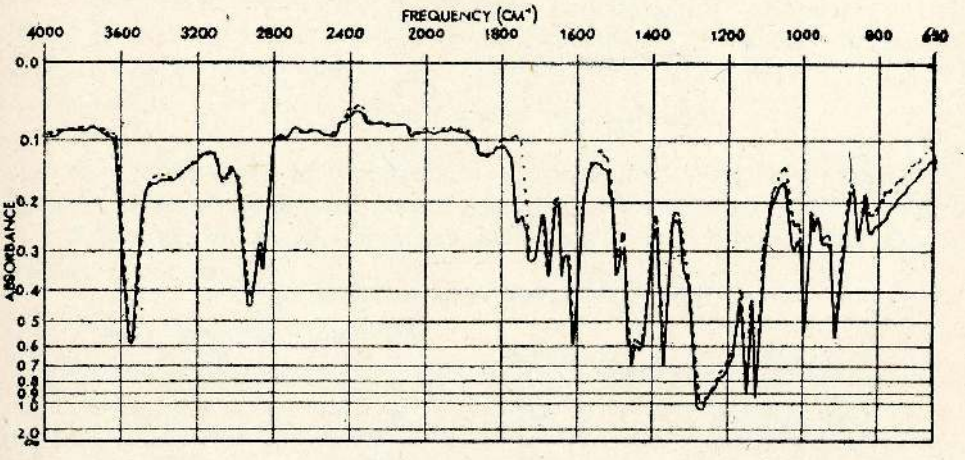


FIGURE 2. Reduction of the intensity of peak 1755 in cinnamon leaf oil caused by the addition of acetyl eugenol to the reference beam.
Continuous line — Cinnamon leaf oil.
Dotted line — Cinnamon leaf oil when compensated with acetyl eugenol.

2.6. Quantitation

The quantitations were made graphically by measuring the absorbance and then using this value to read the percentage from a previously plotted calibration curve. But this method was found to be comparatively tedious as a calibration curve was necessary for every compound. Alternatively, the average value of the absorbance at a selected frequency for a pure component was used to measure the amount of the same substance present in the essential oil by making use of the Beer-Lambert Law.

By this law,

$$I = I_0 e^{-kcl}$$

$$\frac{I_0}{I} = e^{kcl}$$

$$\log_e \frac{I_0}{I} = kcl$$

$$\text{i.e.} \quad A = kcl \qquad (1)$$

where I_0 = Intensity of incident light

I = Intensity of transmitted light

k = Extinction coefficient

c = Concentration in g/l

l = Path length in cm

A = Absorbance or optical density

For a pure substance if the absorbance A is determined for a known c and known l, then equation (1) could be used to find the unknown concentration c' in the essential oil if the absorbance A' of the essential oil is determined for a known or same l.

TABLE 1. Observed absorbance A for path length 0.5 cm (l).

Compound	% Concentration	Absorbance A	Frequency cm^{-1} selected
Eugenol	3.33	0.626	3540
Acetyl eugenol	0.41	0.589	1750
Cinnamyl acetate	0.41	0.840	1730
Benzyl benzoate	0.41	0.765	1715
Cinnamaldehyde	0.41	0.729	1670
Camphor	0.83	0.720	1730
1 : 8 cineole	3.33	0.652	975

2.7. Quantitation technique with changing baseline

In some cases, although there were sharp peaks due to certain single components in the spectra of the essential oil, the direct estimation of that component by making use of equation (1) was not possible. This was due to the baseline of the peak in the spectrum of the essential oil changing markedly from that of the pure component. In such cases, it was possible to obtain an estimate by adding a small quantity (measured amount) of the pure component to the essential oil and measuring the new absorbance. It was found that the addition of a little of the pure component to the essential oil did not in most cases change the baseline of the peak given by the essential oil itself to any appreciable extent. As an example, say the required concentration of a pure substance in the oil is X g/l. Then the absorbance is given by:—

$$A = k\,c\,l = K X \tag{2}$$

In this equation, A can be found experimentally. If a little amount X_0 is added to the oil, with the base line remaining virtually the same, the new absorbance

$$A' = K(X + X_0) \tag{3}$$

Hence, by measuring A', and knowing X_0, X can be found from the two equations (2) and (3).

Our estimation of eugenol in the cinnamon root bark oil was based on this method where we employed the absorbance at 1505 cm^{-1}.

2.8. Quantitation with multiple absorbance

When a certain peak is due to two or more constituents and the constituents are correctly assigned, the additive relationship of absorbance could be used for estimation.[11]

$$A_\lambda = \sum_i k_{i\lambda}\, c_i\, l \tag{4}$$

or for two components

$$A_\lambda = k_{1\lambda}\, c_1\, l + k_{2\lambda}\, c_2 l \tag{5}$$

where both components absorb at the same frequency. In our estimation of 1 : 8 cineole in cinnamon root bark oil, equation (5) was employed. Here, the peak at 975 cm^{-1} is contributed by cinnamaldehyde and 1 : 8 cineole. Since the concentration of cinnamaldehyde can be found from other peaks, this 975 cm^{-1} absorbance gave an easy estimation of 1 : 8 cineole. From equation (5), $A = K_1\, c_1 + K_2\, c_2$. If the subscripts 1 and 2 refer to cinnamaldehyde and 1 : 8 cineole respectively, c_1 can be found by measuring A for the oil and K_1 and K_2 for the pure components.

TABLE 2. Peak assignments for qualitative analysis of cinnamon leaf oil.

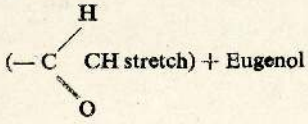
Frequency cm^{-1}	Contributing components
3500 }	Eugenol (O-H stretch)
3400 }	
3065	Eugenol (=C-H stretch aromatic)
3000	Eugenol (alkenes)
2970	Eugenol (aliphatic CH vibrations)
2940	Eugenol
2910	Eugenol (mainly) + Acetyl eugenol, Safrol, Linalool, etc.
2840	Eugenol (mainly) + Acetyl eugenol, Cinnamaldehyde, etc.
2740	Cinnamaldehyde
	
2640	Eugenol
2580	Eugenol
2540	Eugenol
2400	Eugenol
2300	Eugenol
2250	Eugenol
2060	Eugenol
2160	Eugenol
1970	Eugenol
1840	Eugenol
1755	Acetyl eugenol (C = O stretch)
1735	Cinnamyl acetate (C = O stretch)
1715	Benzyl benzoate (C = O stretch)
1675	Cinnamaldehyde + Eugenol (C = O stretch in Cinnamaldehyde)
1635	Eugenol
1600	Eugenol
1510	Eugenol
1490	Eugenol
1460	Eugenol
1450	Eugenol
1430	Eugenol
1365	Eugenol
1270	Eugenol + Benzyl benzoate (C — O — stretch; aryl in both)
1230	(Eugenol + Cinnamyl acetate (C—O—stretch in both)
1210	Eugenol + Acetyl eugenol (C—O—stretch)
1200	Eugenol + Acetyl eugenol (C—O—stretch)
1180 (Sh)	Eugenol
1150	Eugenol
1120	Eugenol
1070	Eugenol
1030	Eugenol (—O CH_3)
990	Eugenol
975	Cinnamaldehyde + Cinnamyl acetate (trans CH deformation)
950	Eugenol (—CH=CH—CH_3)
915	Eugenol + Safrol
850	Eugenol
815	Eugenol
795	Eugenol
745	Eugenol
710	Eugenol
690	Cinnamaldehyde + Cinnamyl acetate

TABLE 3. Peak assignments for qualitative analysis of cinnamon stem bark oil.

Frequency cm^{-1}	Contributing components
3500, 3400	Eugenol + Linalool, Cinnamyl alcohol—OH stretch
3330	Cinnamaldehyde
3070	Cinnamaldehyde
3040	Cinnamaldehyde + Cinnamyl acetate
2970	Eugenol (C-H vibrations)
2940	Cinnamyl acetate + Eugenol
2860	Cinnamyl acetate
2825	Cinnamaldehyde[8] (overtone of the aldehydic bending vibration)
2740	Cinnamaldehyde (Aldehydic C-H stretch)
2450	Cinnamaldehyde
2250	Cinnamaldehyde
1970	Cinnamaldehyde
1950	Cinnamaldehyde
1880	Cinnamaldehyde
1800	Cinnamaldehyde
1730	Cinnamyl acetate (C=O stretch α β unsaturated)
1675	Cinnamaldehyde
1620	Cinnamaldehyde
1600	Cinnamaldehyde
1570	Cinnamaldehyde
1510	Cinnamaldehyde
1490	Cinnamaldehyde + Cinnamyl acetate
1460	Eugenol
1450	Cinnamaldehyde + Cinnamyl acetate
1385	Cinnamyl acetate
1365	Cinnamyl acetate
1330	Cinnamaldehyde
1300	Cinnamaldehyde
1270	Eugenol
1250	Cinnamaldehyde
1240	Cinnamyl acetate + Eugenol
1210	Cinnamyl acetate + Cinnamaldehyde + Eugenol
1180	Cinnamaldehyde
1160	Cinnamaldehyde
1150	Cinnamaldehyde + Eugenol
1120	Cinnamaldehyde
1070	Cinnamaldehyde
1030	Cinnamyl acetate + Eugenol
1010	Cinnamaldehyde
970	Cinnamaldehyde + Cinnamyl acetate (trans CH deformation)
910	Cinnamaldehyde + Eugenol
850	Cinnamaldehyde + Eugenol
820	Cinnamyl acetate
745	Cinnamaldehyde + Cinnamyl acetate
690	Cinnamaldehyde + Cinnamyl acetate

TABLE 4. Peak assignments for cinnamon root bark oil.

Frequency cm^{-1}	Contributing compounds
3540, 3400	Eugenol, Terpineol
3070	Cinnamaldehyde, Eugenol
2960	Camphor, 1 : 8 Cineole, Eugenol
2900	Camphor, 1 : 8 Cineole, Terpineol, Eugenol
2875	Camphor
2740	Cinnamaldehyde
1740	Camphor
1675	Cinnamaldehyde
1620	Cinnamaldehyde
1600	Cinnamaldehyde, Eugenol
1505	Eugenol
1450	Camphor, 1 : 8 Cineole, Terpineol, Cinnamaldehyde
1415	Camphor
1390	Camphor, 1 : 8 Cineole
1370	Camphor, 1 : 8 Cineole, Terpineol, Eugenol
1320	Camphor
1300	Camphor 1 : 8 Cineole, Cinnamaldehyde, Terpineol
1270	Camphor, 1 : 8 Cineole, Eugenol
1240	1 : 8 Cineole, Eugenol
1210	Eugenol
1200	Eugenol
1165	1 : 8 Cineole, Terpineol
1150	Eugenol, Terpineol
1135	Cinnamaldehyde, Eugenol, Terpineol
1120	Eugenol, Terpineol, Cinnamaldehyde
1095	Camphor
1080	1 : 8 Cineole, Cinnamaldehyde
1045	Camphor, 1 : 8 Cineole
1020	Camphor, 1 : 8 Cineole, Eugenol
980	1 : 8 Cineole, Cinnamaldehyde
950	Camphor, Cinnamaldehyde, Terpineol
935	Terpineol
910	Eugenol, Terpineol
890	1 : 8 Cineole
845	1 : 8 Cineole, Eugenol
815	Terpineol
795	Eugenol
745	Camphor, Cinnamaldehyde, Eugenol
690	Cinnamaldehyde

TABLE 5. Comparison of results by IR and GLC methods.

(I) Cinnamon leaf oil

Compound	Percentage	
	by IR	by GLC
Eugenol	79.9	80.0
Acetyl eugenol	3.7	2.1
Cinnamyl acetate	3.2	1.8
Benzyl benzoate	4.5	3.4
Cinnamaldehyde	2.0	2.4

(II) Cinnamon bark oil

Compound	Percentage	
	by IR	by GLC
Cinnamaldehyde	63.5	63.0
Cinnamyl acetate	13.0	5.0
Eugenol	8.0	10.0

(III) Cinnamon root bark oil

Compound	Percentage	
	by IR	by GLC
Camphor	52.5	59.9
1 : 8 Cineole	12.0	19.2
Eugenol	5.0	5.0
Cinnamaldehyde	3.3	3.9

3. Results and Discussion

3.1. Cinnamon leaf oil

The infra-red spectrum of a sample of Sri Lanka cinnamon leaf oil is strikingly similar to the spectrum of eugenol, its main constituent (Figures 3 and 4). However, the appearance of four distinct peaks in the carbonyl region (1750-1670 cm^{-1}) readily distinguishes cinnamon leaf oil from eugenol. The OH stretching frequency at 3540 cm^{-1} is suitable for quantitative assay of eugenol in cinnamon leaf oil, as contributions from other hydroxylic compounds are negligible. The peak due to OH (stretch) appears as a broad band in the spectrum from a film of the oil, but in spectra from dilute solutions of the oil in many organic solvents, it becomes narrow and sharp. In 3.33% chloroform solutions employed in this study, it gave a reproducible absorbance of 0.626 for a path length of 0.5 mm. Accordingly, this peak was used to estimate the eugenol content of cinnamon leaf oil, using the Beer-Lambert relationship. After each estimation, the differential spectrum of the leaf oil was recorded with the estimated amount of eugenol added to the solvent in the reference beam.

The complete disappearance of all peaks assignable to eugenol confirmed the accuracy of the estimation. When the estimate was incorrect, i.e. when it was too high, or too low, this was indicated by the appearance of negative or residual peaks respectively. Beside the OH stretch peak at 3540 cm^{-1}, other sharp peaks due to eugenol could also be employed for its quantitation. Beside eugenol, all other peak assignments too were confirmed in similar fashion by differential spectra. By this means, several assignments reported by Bellanato and Hidalgo[2] were found to be erroneous. These authors have assigned peaks at 2910 and 2840 cm^{-1} as due to eugenol, but in fact other compounds are also partly responsible for these peaks (Table 2). Likewise, the peak at 2740 cm^{-1} again assigned only to eugenol has a contribution from cinnamaldehyde as well (aldehyde C-H stretch).

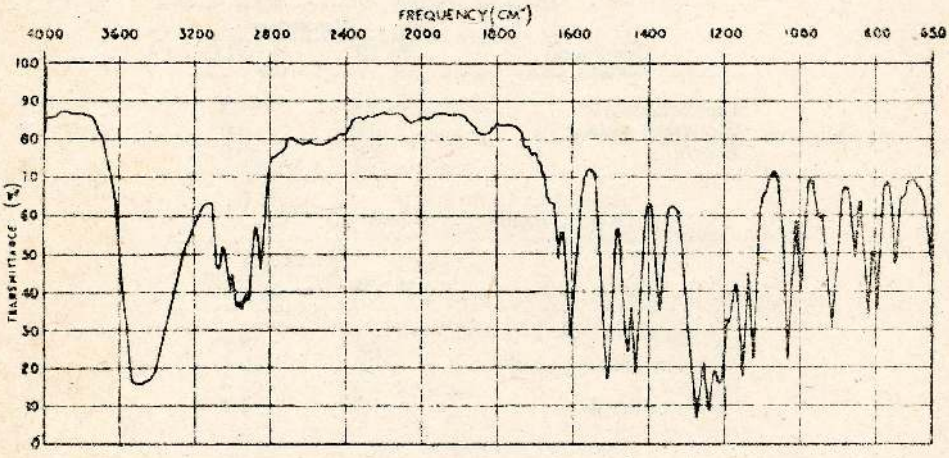


FIGURE 3. Spectrum of eugenol.

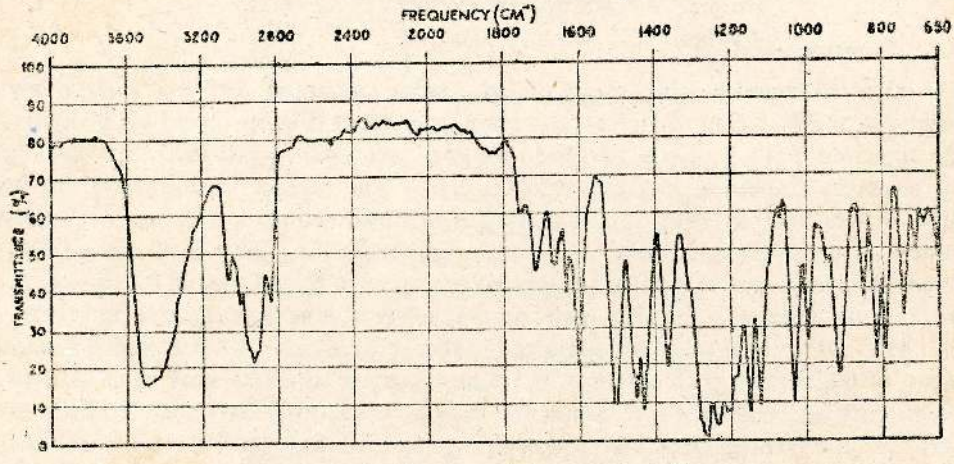


FIGURE 4. Spectrum of cinnamon leaf oil.

In the carbonyl region, there are four peaks which appear at 1755, 1735 (shoulder) 1715 and 1675 cm^{-1}. Using the methods described above, these have been confirmed as substantially due to acetyl eugenol, cinnamyl acetate, benzyl benzoate and cinnamaldehyde respectively. The presence of acetyl eugenol and benzyl benzoate as a constituent of cinnamon leaf oil has not been recorded by Bellanato and Hidalgo[2] in their IR studies. Although Angmor *et al*[2] report the presence of acetyl eugenol in their GLC studies on cinnamon leaf oil, they do not record the presence of benzyl benzoate. However, it has been reported in the early work of Guenther[7] and Glichitch[6] and confirmed recently by GLC studies as well.[12] The 1675 cm^{-1} peak is not solely due to cinnamaldehyde, there being a very small contribution to it from eugenol. Previous assignment[2] of the peak 1630 cm^{-1} as due to cinnamyl acetate is incorrect, as there is no peak at 1630 in the IR spectrum of pure cinnamyl acetate. The peak 1510 cm^{-1} previously assigned to safrole is due to both eugenol and safrole. It has been noticed that intense peaks in the spectra of benzyl benzoate, cinnamyl acetate and acetyl eugenol are at 1270, 1230 and 1210 cm^{-1} respectively. Hence in the spectrum of cinnamon leaf oil in which these compounds are present, there should be certain contributions in the carbonyl region due to each of them. This was verified by means of differential spectra. Further, the 975 cm^{-1} peak has been found to be due to cinnamaldehyde as well as to cinnamyl acetate and cinnamyl alcohol. This intense peak is due to *trans* CH deformation.

3.2. Cinnamon stem bark oil

Of the three essential oils obtainable from cinnamon, cinnamon stem bark oil is the most expensive. This is due to its pleasant and acceptable aroma and its use in the food and beverage industries. The major constituent of cinnamon bark oil is cinnamaldehyde and in the infra-red spectrum of cinnamon stem bark oil, the dominant peaks are due to it (Figures 5 to 8). Some peaks due to cinnamyl acetate, eugenol and linalool are also displayed depending on the quality of the oil. The content of cinnamaldehyde and even the authenticity of cinnamon stem bark oil could be readily evaluated from an infra-red spectrum of it in the form of a film. The infra-red spectra of good quality cinnamon stem bark oil bears a striking resemblance to that of cinnamaldehyde (Figures 5 and 6). Here, the intensities of the peaks 2740 cm^{-1} (medium) 1675 cm^{-1} (strong) and 975 cm^{-1} (strong) agree very closely to those of cinnamaldehyde. In certain samples of the oil the terpenic fraction was found to be high thereby reducing its quality. This may be due to faulty distillation or the use of immature bark for distillation. In this case, the intensities of C-H stretching absorptions which appear in the range 2970-2945 cm^{-1} are very much higher (Figure 7). Also, the peaks 2740 and 1670 cm^{-1} become reduced in intensity. These peaks are due to aldehydic C-H stretch and carbonyl stretch from cinnamaldehyde. Sometimes the bark is distilled along with twigs, in which case the quality of the oil becomes poorer and the oil thus obtained is known in Sri Lanka as "katta thel" (Figure 8). This oil contains a higher amount of eugenol and is readily detectable as there are

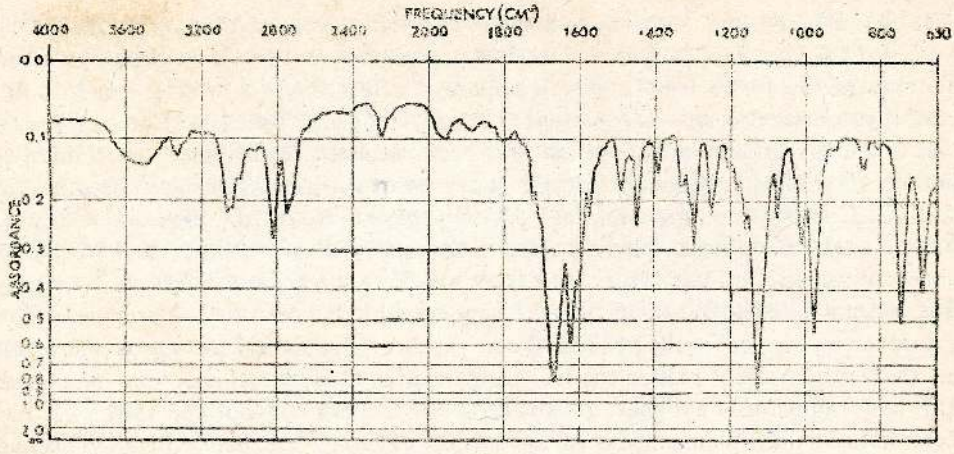


FIGURE 5. Spectrum of cinnamaldehyde.

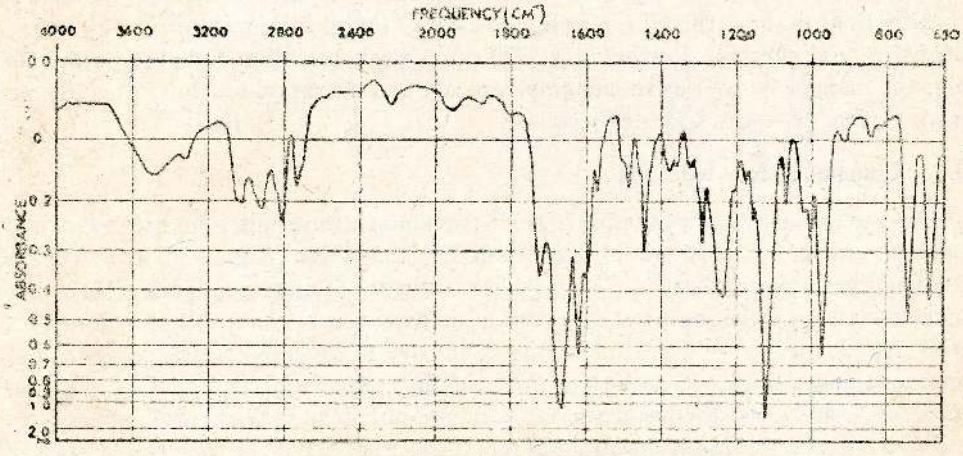


FIGURE 6. Spectrum of cinnamon stem bark oil.

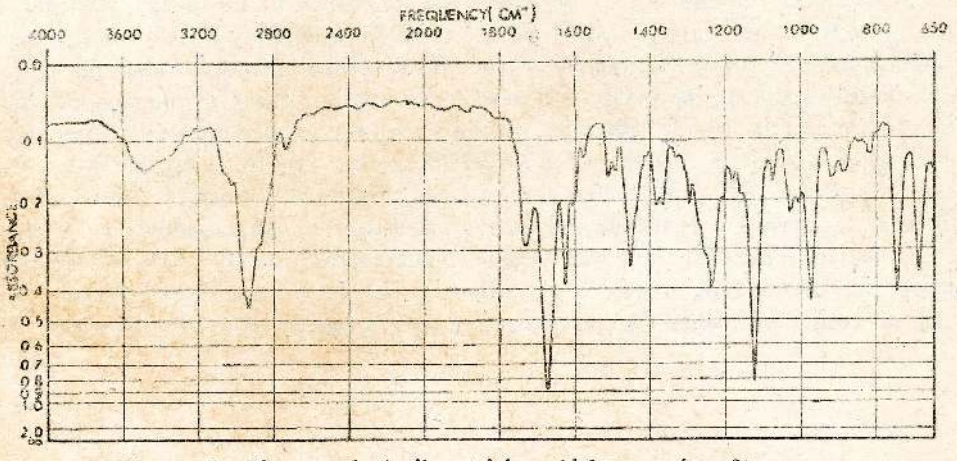


FIGURE 7. Cinnamon bark oil containing a high proportion of terpenes.

enhanced eugenol peaks 3540, 1500, 1420, 1270, 1230 and 1030 cm^{-1}. A similar situation arises when there are adulterations of cinnamon stem bark oil with the cheaper leaf oil. In this case too eugenol peaks become prominent. The broad band 3540-3400 cm^{-1} is contributed by eugenol and other hydroxylic compounds present such as linalool and cinnamyl alcohol. However, it has been assigned previously[2] as due to eugenol entirely. Similarly, previous assignment of peaks at 3040, 2940, 2860, 1620, 1510, 1490, 1450, 1385, 1250, 1240, 1210, 1180, 1150, 820 and 690 cm^{-1} were found to be erroneous, and the correct assignments are given in Table 3. Our assignments are based on the methods discussed previously (**2. 4**). The quantitation of cinnamaldehyde was carried out by using the peak at 2740 cm^{-1}. This could also be achieved from a graph of absorbance versus percentage of cinnamaldehyde. The carbonyl absorbance at 1675 cm^{-1} could as well be employed for this purpose.

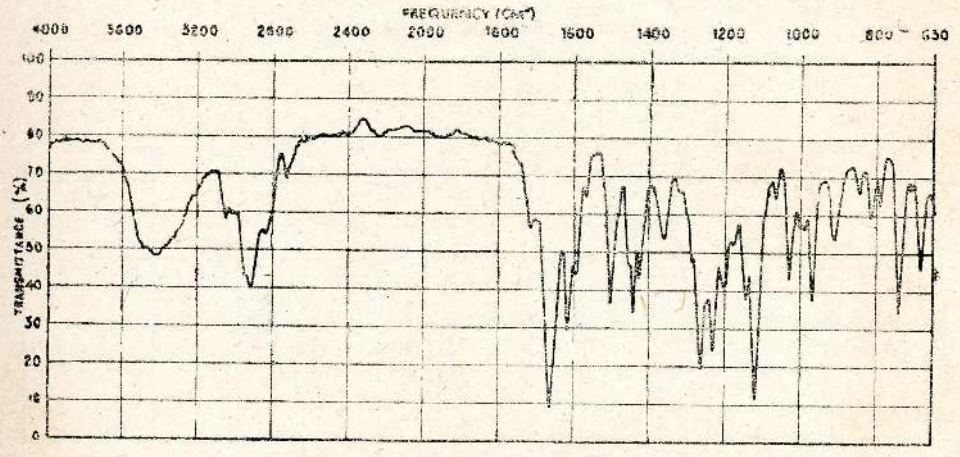


FIGURE 8. Cinnamon bark oil of poor quality ("Katta Thel").

3.3. Cinnamon root bark oil

The infra-red spectrum of cinnamon root bark oil appears very similar to that of camphor, the principal constituent in it (Figures 9 and 10); there are additional peaks due to 1 : 8 cineole and others. The estimation of camphor in root bark oil was accomplished by using the carbonyl absorbance at 1740 cm^{-1}, and cinnamaldehyde and 1 : 8 cineole by use of the absorbance at 1675 cm^{-1}, and 980 cm^{-1} respectively. Since the peak at 980 cm^{-1} is contributed by both cinnamaldehyde and 1 : 8 cineole, the estimation of 1 : 8 cineole was achieved by using the method described earlier (**2.4**). The eugenol content was estimated by using the method discussed in **2.8**.

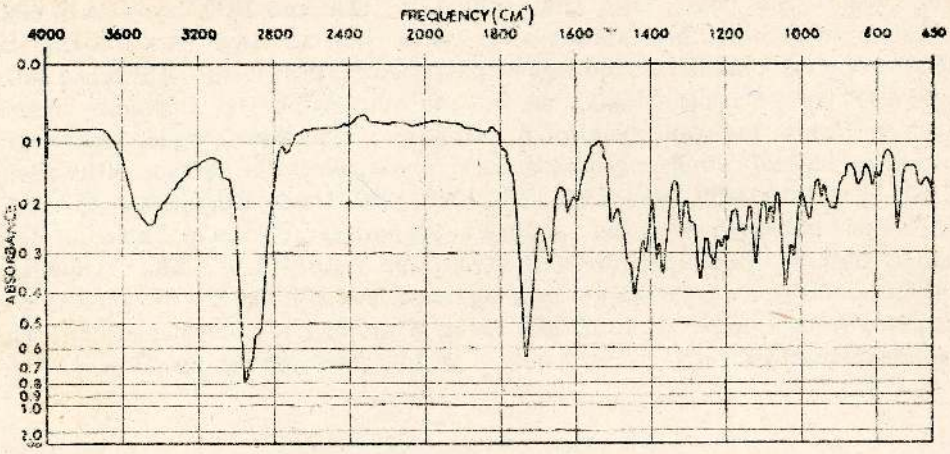


FIGURE 9. Spectrum of root bark oil.

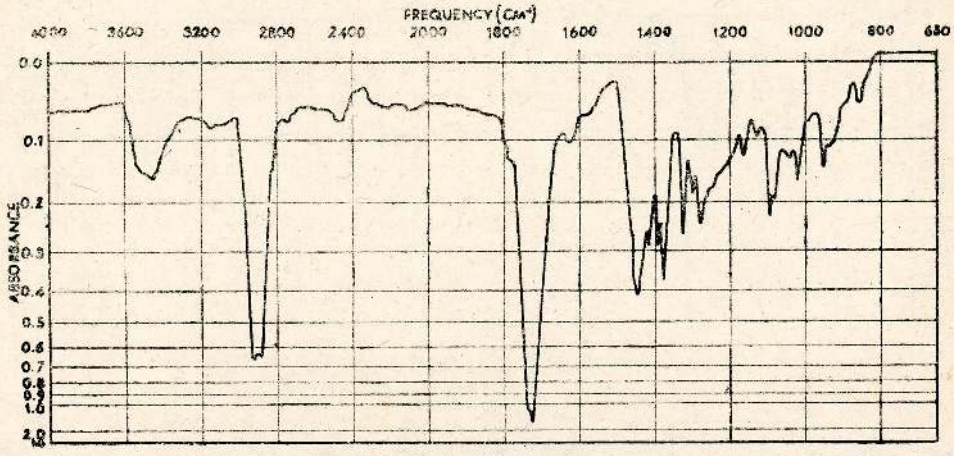


FIGURE 10. Spectrum of camphor.

4. Conclusion

IR spectroscopy can be employed to give a rapid and accurate estimate of the principal constituents of the essential oils of cinnamon. The method affords another valuable parameter in the assessment of quality in essential oils, and is particularly suitable for routine application.

Acknowledgements

This work has been partly supported by grants from the Ministry of Plantation Industries and the National Science Council of Sri Lanka. The authors are grateful to Miss Clodagh Nethsingha, Chief Librarian, C.I.S.I.R. for assistance with the literature, to Mrs. Shirani Colombage and Mr. P.C.M. Fernando for help in the preparation of the manuscript and to Mr. L. N. Fernando for valuable technical assistance in regard to the infra-red spectroscopic methods.

References

1. Angmor, J. E., Dicks, D. M., Evans, W. C. & Santra, D. K. (1972) *Planta Med.* **21** (4): 416-420.
2. Bellanato, J. & Hidalgo, A. (1971) *Infra-red analysis of essential oils.* London : Heyden.
3. Carroll, M. F. & Price, W. J. (1964) *Perfum. Essent. Oil Rec.* **55** : 394-395.
4. Das Gupta, S. & Bhattacharya, S. C. (1956) *Perfum. Essent. Oil Rec.* **47**: 197-198.
5. Farnov, H. (1969) *Qualitas Pl. Mater. Veg.* **18** (1-3) : 110-115.
6. Glichitch, L. S. (1925) *Parfum. Fr.* (27) : 117-130.
7. Guenther, E. (1950) *The essential oils*, Vol. 4, p. 234. New York : Van Nostrand.
8. Pinchas, S. (1955) *Analyt. Chem.* **27** : 2-6.
9. Rao, C. N. R. (1963) *Chemical applications of infra-red spectroscopy*, p. 535. London : Academic Press.
10. Rao, C. N. R. (1963) *Ibid.*, pp. 97, 98, 535.
11. Rao, C. N. R. (1963) *Ibid.*, p. 534.
12. Wijesekera, R.O.B., Jayewardene, A.L. & Rajapakse, L.S.(1974)*J. Sci. Fd Agric.***25**: in press.
13. Wijesekera, R. O. B., Jayewardene, A. L. & Fonseka, B. D. (1973) *Phytochem.* **12** : 2697-2704.
14. Wijesekera, R. O. B. (1972) *Proc. Ceylon Ass. Advmt Sci.* **28** (2) : 122-146.
15. Wijesekera, R. O. B. (1973) *J. Natn. Sci. Coun. Sri Lanka* **1** (2) : 67-81.
16. Wijesekera, R. O. B. & Fonseka, K. H. (1973) *Proc. Inst. Chem. Sri Lanka* **2** : 41-44.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 51 — 55.

On Generalized Inverse of a Linear Operator

P. W. EPASINGHE*

Department of Statistics, Florida State University, Tallahasse, Florida 32306, *U.S.A.*

(*Paper accepted :* 18 *April* 1974)

Abstract : The concept of a generalized inverse of a rectangular matrix is characterized by using properties of the vector spaces involved. It is then extended for linear operators from one vector space to another when the spaces involved are infinite dimensional.

The concept of a generalized inverse of a given m × n matrix A has appeared in the literature[1–4] since 1920 and has been defined by Rao[5–6] as follows:

Definition 1. Let A be an m × n matrix of arbitrary rank. A *generalized inverse* of A is an n × m matrix G such that $x = Gy$ is a solution of $Ax = y$ for any y which makes the equation consistent.

In the above definition, x, y are respectively elements of $E^{(n)}$, $E^{(m)}$ which are respectively the linear spaces of complex column vectors with n, m rows.

Rao and Mitra[6] have derived several properties of generalized inverses, referred to as g-inverses, by purely algebraic techniques.

It is possible to give a geometrical characterization to a g-inverse. One advantage of this geometrical characterization is that the results can immediately be extended to linear operators from one space to another space, when the spaces involved are not necessarily finite dimensional. We handle first, the case considered by Rao and Mitra, and then proceed to show how the concept can be extended to linear operators.

The given m × n matrix A may be considered as a linear mapping of $E^{(n)}$ into $E^{(m)}$. Let N(A) be the null space of A i.e. N(A) is the set of all $x \in E^{(n)}$ such that $Ax = 0$, the additive identity of $E^{(m)}$. Then we have the following elementary result :—

Lemma 1. The rank of A is n if the dimension of N(A) is zero.

In this case, when N(A) is zero dimensional, $Ax = y$ will have a unique solution for x, for any y for which this is consistent. This unique solution is given by $x = A_L^{-1}y$ where $A_L^{-1} = (A^*A)^{-1}A^*$ is a left inverse[7] of A.

*On sabbatical leave from the University of Sri Lanka, Vidyodaya Campus, Nugegoda, on a Fulbright Post Doctoral Fellowship.

Let us consider the case when N(A) is not zero dimensional. If its dimension is r, then $0 < r \leq n$, since N(A) is a subspace of $E^{(n)}$. Let $\{x_1, x_2, \ldots, x_r\}$ be a basis for N(A). Then $E^{(n)}$ has a basis of the form $\{x_1, x_2, \ldots, x_r, x_1^{(1)}, x_2^{(1)}, \ldots, x^{(1)}_{n-r}\}$, with obvious modifications if $r = n$. In the following discussion we will always assume that $r < n$, because if $r = n$, the only y for which $Ax = y$ is consistent is $y = 0$, and any $x \in E^{(n)}$ is a solution. The following results are then obtained :—

Lemma 2. The set $\{Ax_1^{(1)}, Ax_2^{(1)}, \ldots, Ax^{(1)}_{n-r}\}$ is linearly independent.

$$\sum_{i=1}^{n-r} \lambda_i A x_i^{(1)} = 0 \Rightarrow A \sum_{i=1}^{n-r} \lambda_i x_i^{(1)} = 0$$

$$\Rightarrow \sum_{i=1}^{n-r} \lambda_i x_i^{(1)} \in N(A) \Rightarrow \sum_{i=1}^{n-r} \lambda_i x_i^{(1)} = \sum_{i=1}^{r} \mu_i x_i$$

$$\Rightarrow \lambda_1 = \lambda_2 = \ldots = \lambda_{n-r} = \mu_1 = \mu_2 = \ldots = \mu_r = 0$$

since $\{x_1, x_2, \ldots, x_r, x_1^{(1)}, x_2^{(1)}, \ldots, x^{(1)}_{n-r}\}$ is a linearly independent set.

Lemma 3. The set $\{Ax_1^{(1)}, Ax_2^{(1)}, \ldots, Ax^{(1)}_{n-r}\}$ is a basis for the range M(A) of A.

If $y \in M(A)$, then $\exists\, x \in E^{(n)}$ such that $Ax = y$.

But $x = \sum_{i=1}^{r} \lambda_i x_i + \sum_{i=1}^{n-r} \mu_i x_i^{(1)}$ for suitable scalars $\lambda_1, \lambda_2, \ldots, \lambda_r, \mu_1, \mu_2, \ldots, \mu_{n-r}$.

$$\therefore y = \sum_{i=1}^{n-r} \mu_i (Ax_i^{(1)}) \text{ since } Ax_1 = Ax_2 = \ldots = Ax_r = 0.$$

Lemma 4. If R(A) is the subspace (of $E^{(n)}$ spanned by the set $\{x_1^{(1)}, x_2^{(1)}, \ldots, x^{(1)}_{n-r}\}$, then the linear mapping $A : R(A) \to M(A)$ is one-one and onto.

Hence there is a unique linear mapping $A^- : M(A) \to R(A)$ which is the inverse of the mapping $A : R(A) \to M(A)$. Now, we have the following theorem :—

Theorem 1. If y is any vector for which $Ax = y$ is consistent, then $x = A^- y$ is a solution of the equation $Ax = y$, and therefore A^- is a g-inverse of A.

At this stage it is worthwhile to note that, although the linear mapping A^-: M(A) → R(A) defined is unique, its matrix representation is not. For instance, if $[A^-]_{n\times m}$ is any n × m matrix satisfying the requirement, and $[N]_{n\times m}$ is any n × m matrix which maps M(A) into the null vector of $E^{(n)}$, then $[A^-]_{n\times m} + [N]_{n\times m}$ is also a matrix representation of the mapping A^-.

It is easily seen that each extension of a basis for N(A) to form a basis for $E^{(n)}$ provides us with one g-inverse. Conversely, suppose B is a n × m matrix such that, for each $y \in M(A)$, $Ax = y$ is satisfied by $x = By$. Let $\{y_1, y_2, \ldots y_{n-r}\}$ be a basis for M(A). Then $\{z_i = By_i, i = 1, 2, \ldots, n-r\}$ is a set of n − r linearly independent vectors belonging to $E^{(n)}$. Further $\{x_1, x_2, \ldots, x_r, z_1, z_2, \ldots, z_{n-r}\}$ is set of n linearly independent vectors belonging to $E^{(n)}$ and hence forms a basis for $E^{(n)}$. Therefore, $\{x_i \mid i = 1, 2, \ldots, r\} \cup \{z_i \mid i = 1, 2, \ldots, n-r\}$ is an extension of the basis $\{x_i \mid i = 1, 2, \ldots, n\}$ of N(A) to form a basis for $E^{(n)}$. This, as we know, gives rise to a unique g-inverse of A, and B is one of its matrix representations.

The possible non-uniqueness of the matrix representation of A^- may appear to give rise to a certain amount of confusion. However, the following result[6] gives a simple relationship among all the matrix representations.

Lemma 5. If $[A^-]_{n\times m}$ is one matrix representation of a g-inverse of A, then every matrix representation of every g-inverse of A is of the form $[A^-]_{n\times m} + [N]_{n\times m}$ where N is an n × m matrix satisfying the condition $ANA = 0$ as a n × n matrix equation. Conversely, for every such N, $[A^-]_{n\times m} + [N]_{n\times m}$ is a generalized inverse of A.

This follows from Lemma 2.2.1 of Rao and Mitra.[6]

What all this shows is that we have generated the set of all g-inverses of the m × n matrix A. Each such g-inverse has an n × m matrix representation and hence may be considered as a linear mapping of $E^{(m)}$ into $E^{(n)}$. Since M(A) is an n–r dimensionl subspace of $E^{(m)}$, and each A^- maps M(A) onto an n–r dimensional subspace of $E^{(n)}$, it is clear that the rank of A^- is not less than n–r which is the rank of A. Hence rank $(A^-) \geq$ rank A.

Now we attempt to extend the above characterization to a general linear operator A which maps a given linear vector space V into another linear vector space W, both spaces assumed to be infinite dimensional to avoid unnecessary complications in notation. The following definitions and theorems[8] pertaining to infinite dimensional linear vector spaces are quoted for completeness.

Definition 2. A set {x} of vectors of an infinite dimensional linear vector space is said to be *linearly independent* if every finite subset of {x} is linearly independent. Otherwise, the set {x} is said to be *linearly dependent*.

Definition 3. A linearly independent set $\{x\}$ of vectors of a linear vector space V is called a *Hamel basis*, if given any $v \in V$, $\exists$ a finite subset $\{x_1, x_2, \ldots, x_k\}$ of $\{x\}$ and scalars $\lambda_1, \lambda_2, \ldots, \lambda_k$, such that

$$v = \sum_{i=1}^{k} \lambda_i x_i$$

Lemma 6. Every linear space has a Hamel basis. Each vector is a unique linear combination of a finite number of vectors of the Hamel basis.

Lemma 7. If U is a subspace of V, and $\{x\}$ is a Hamel basis for U, then V has a Hamel basis $\{y\}$ such that $\{x\} \subset \{y\}$. In other words, every linearly independent set of vectors of V can be extended to form a Hamel basis for V.

Now, let us consider a linear operator A which maps V into W, V and W both being infinite dimensional. The set of all $v \in V$ such that $Av = 0$, the additive identity of W, is a linear subsepace N(A) of V. We will call N(A), the *null space* of A.

Lemma 8. If the null space of A is zero dimensional, then the equation $Ax = y$ where $x \in V, y \in W$ has a unique solution for each y for which $Ax = y$ is consistent.

If M(A) is the range of A, then the mapping $A : V \to M(A)$ is one-one and onto Hence, there is a unique inverse mapping $A^- : M(A) \to V$. Therefore, given $y \in M(A)$, $x = A^- y$ is the unique solution of $Ax = y$.

Let us now consider the case when N(A) is not zero dimensional. Here again, if $N(A) = V$, then the only y for which $Ax = y$ is consistent is $y = 0$, and therefore for an arbitrary linear operator B from W into V, $x = By$ is a solution of the equation of the equation $Ax = y$. Hence, in the following discussion, we assume that N(A) is a proper subspace of V.

Let $\{x\}$ be a Hamel basis for N(A), which exists by Lemma 5. Then by Lemma 6, V has a Hamel basis of the form $\{x\} \cup \{x^{(1)}\}$.

Lemma 9. $\{Ax^{(1)}\}$ is a linearly independent set.

If $\{Ax_1^{(1)}, Ax_2^{(1)}, \ldots\ldots, Ax_n^{(1)}\}$ is any finite subset of elements of the above set, then,

$$\sum_{i=1}^{n} \lambda_i \, Ax_i^{(1)} = 0 \Rightarrow A \sum_{i=1}^{n} \lambda_i x_i^{(1)} = 0$$

$$\Rightarrow \sum_{i=1}^{n} \lambda_i x_i^{(1)} \in N(A) \Rightarrow \exists \text{ a finite subset}$$

$\{\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_m\}$ of elements of $\{\mathbf{x}\}$ and scalars $\mu_1\ \mu_2, \ldots, \mu_m$ such that

$$\sum_{i=1}^{n} \lambda_i \mathbf{x}_i^{(1)} = \sum_{i=1}^{m} \mu_i \mathbf{x}_i \Rightarrow \lambda_1 = \lambda_2 = \ldots = \lambda_n = \mu_1 = \mu_2 = \ldots \mu_m = 0,$$

by the linear independence of the set $\{\mathbf{x}\} \cup \{\mathbf{x}^{(1)}\}$.

Lemma 10. $\{A\mathbf{x}^{(1)}\}$ is a Hamel basis for M(A), the range of A.

Proof as in Lemma 3, with obvious modifications in notation.

Lemma 11. If R(A) is the subspace (of V) spanned by the linearly independent set $\{\mathbf{x}^{(1)}\}$, then the linear mapping $A : R(A) \to M(A)$ is one-one and onto.

Hence, there exists a unique linear operator $A^- : M(A) \to R(A)$ which is the inverse mapping of $A : R(A) \to M(A)$.

Definition 4. A^- defined above is called a g-inverse of A.

It is seen that each extension of a basis of N(A) to form a basis of V, provides us with one g-inverse of A. The last result we have is as follows :

Theorem 2. If $A : V \to W$ is a linear mapping of a linear vector space V into a linear vector space W, then $\exists$ a linear operator A^- such that, for each $\mathbf{y} \in W$ for which $A\mathbf{x} = \mathbf{y}$ is consistent, $\mathbf{x} = A^-\mathbf{y}$ is a solution of the equation $A\mathbf{x} = \mathbf{y}$.

Acknowledgements

The author wishes to acknowledge with thanks the award of a grant by the State Department of the United States for advanced study and research sponsored under the Fulbright-Hays Act. He is also grateful to Professor Ralph A. Bradley for hospitality at the Statistics Department of the Florida State University, where this work was done, while being supported by funds provided under the above grant.

References

1. Moore, E. H. (1920) *Bull. Am. Math. Soc.* **26** : 394-395.
2. Moore, E. H. (1935) *General analysis*. Philadelphia : American Philosophical Society.
3. Penrose, E. (1955) *Proc. Camb. Phil. Soc. Math. & Phys. Sci.* **51** : 406-413.
4. Penrose, R. (1956) *Proc. Camb. Phil. Soc. Math. & Phys. Sci.* **52**: 17-19.
5. Rao, C. R. (1962) *J. R. Statist. Soc. Ser. B.* 24 : 152-158.
6. Rao, C. R. & Mitra, S. K. (1971) *Generalized inverse of matrices and its applications*, p. 20. New York : John Wiley.
7. Rao, C. R. & Mitra, S. K. (1971) *Ibid.*, p. 19.
8. Wilansky, A. (1964) *Functional analysis*. New York : Blaisdell Publishing Co.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 57—65.

Cyanide Liberation from Linamarin

E. R. JANSZ, E. E. JEYARAJ, NIRMALA PIERIS* AND D. J. ABEYRATNE

Ceylon Institute of Scientific and Industrial Research (CISIR), P. O. Box 787, Colombo 7, Sri Lanka.

(*Paper accepted : 29 April* 1974)

Abstract : Several plant materials were tested for cyanide liberating capacity. Two of these materials were able to liberate cyanide from purified linamarin. However, the mechanism of liberation appears to be dissimilar to that of the linamarase of manioc. Although ginger cannot liberate significant amounts of cyanide from purified linamarin, some samples have been found to release it from boiled manioc. In this case too this effect does not appear to be due to a "manioc-type" linamarase. Coliforms cannot liberate HCN from linamarin. A reputed antidote for manioc poisoning, guava leaf extract, contains a potent linamarase inhibitor. Further details on acid and enzymic hydrolysis of linamarin are also reported.

1. Introduction

Linamarin is one of a group of compounds known as the cyanogenic glucosides (Figure 1). These compounds occur widely in plants, notably in manioc, *Manihot esculenta* Crantz. Linamarin (R_1, $R_2 = CH_3$) is the major cyanogenic glucoside of manioc, comprising 93 % of the total cyanogenic glucosides,[4] the rest being made up by lotaustralin ($R_1 = CH_3$, $R_2 = C_2H_5$).

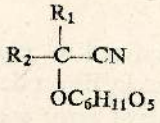


FIGURE 1.

Linamarin on hydrolysis produces hydrogen cyanide ; this reaction is of interest in connection with : (1) methods of assay of total cyanide and (2) the fate of linamarin after ingestion.

Assay of linamarin is usually performed after acid hydrolysis or enzymic hydrolysis (linamarase). Some studies on the assay of linamarin have been previously communicated by this group.[2,7,8] This paper presents further results using model systems.

Processed manioc contains considerable quantities of cyanogenic glucosides and it has been shown that in some instances a lethal dose of cyanide can be produced if all the linamarin ingested is hydrolysed to HCN. [7] It has been suggested that uncooked vegetables,[6] gut flora[5] or even intestinal enzymes[1] can bring about this reaction. This

*The studies on boiled manioc form a part of a M.Sc. dissertation (University of Sri Lanka, Colombo Campus) of Nirmala Pieris.

paper includes a preliminary survey of the cyanide liberating capacity of some plant materials which are generally consumed in a raw or semi-cooked state, where the method of preparation may not be expected to destroy all enzyme activity.

2. Experimental

2.1. Preparation of material

Linamarin and linamarase were prepared by the method of Wood.[11] Boiled manioc was prepared as described previously.[7] Vegetable extracts (from 10 to 15 g fresh weight) were prepared either by homogenisation in a Waring blendor or by grinding in a mortar with aqueous 0.1M citrate buffer at approximately tissue pH.

2.2 Acid hydrolysis of linamarin

Linamarin (30 to 40 mg) was steam distilled with acid of the appropriate normality keeping the volume of the distilled fluid unchanged. Total time for the operation was 90 min within which 200 ml distillate was collected in 25 ml of 2.0% NaOH. Residual linamarin was determined by adjusting the pH to 5, adding 300 units of linamarase and 10 ml of citrate buffer (0.2M, pH 5.0) followed by incubating for 18 h at room temperature. The HCN formed was distilled and collected as described above.

2.3. Assays

Linamarin, linamarase and HCN were assayed as described previously.[7,10,11]

3. Results

3.1. Studies with model systems

The basic method of Wood,[11] modified as reported previously,[7] for studying the linamarase-linamarin enzyme system by direct determination of HCN in the reaction mixture was tried out. The standard error was within 6%. Typical time-course curves for the reaction at two substrate concentrations which are (a) limiting and (b) sufficient to saturate the enzyme are shown in Figure 2.

The method has been applied in this study to test the effect of vegetable proteins on linamarase activity and the effect of some bacteria on linamarin. It has not been more widely used because, unless the material under consideration is freed of sugars and other small molecules which interfere with the picrate test, blanks are unacceptably high. For this reason hydrogen cyanide liberation from crude extracts was always assayed after distillation into Na_2CO_3.[7]

3.2. Acid hydrolysis

Results of these studies have been reported earlier.[2] More detailed studies have since revealed that the yield of HCN by hydrolysis of linamarin by linamarase was quantitative (100% recovery) and that the 83% yield reported in that paper[2] for the enzyme reaction was due to an error in the standard curve caused by effect of NaOH

on the picrate-cyanide colour reaction. Due to this the values for acid hydrolysis increase proportionately ; the best yield by acid hydrolysis being brought about by 7N H_2SO_4 which gives a yield of 68%. It should, however, be noted that the use of lower acid concentrations results in considerable quantities of residual glucoside. Better overall yields might be obtained by increasing the reaction time when using the lower acid concentrations.

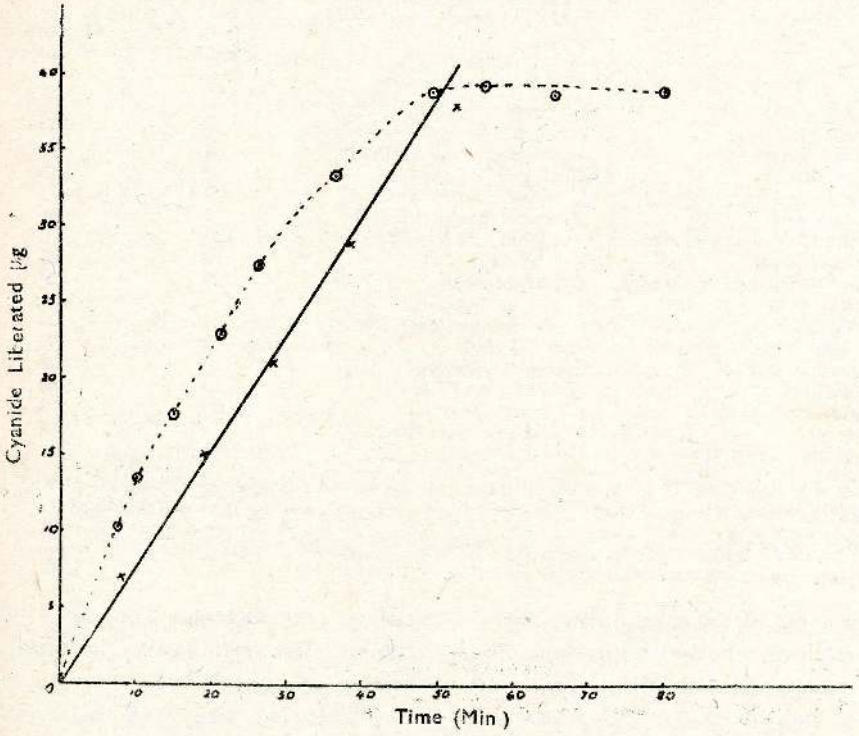


FIGURE 2. Liberation of cyanide from linamarin.

The reaction mixtures contained:

(*a*) 0——0 linamarin, 3.5 mg ; linamarase, 15 units ;

(*b*) x——x linamarin, 5.0 mg ; linamarase, 4 units ;

in a reaction volume of 5 ml, 0.08 M with respect to citrate buffer (pH 5.0).

Aliquots used for assay were 0.5 and 1 ml respectively.

3.3. Effect of vegetable juices on linamarin

Seventeen vegetables, chosen because they are commonly eaten raw, or semi-cooked, or because they are in some way associated with manioc consumption, were tested for cyanide liberating capacity. In a preliminary set of results (Table 1), it was found that only in 4 cases was cyanide liberated from linamarin. The results also show that in

many of the 17 cases it was possible to account for all the linamarin added (within 10%) either as cyanide or residual linamarin. Deviations were observed with ginger rhizome, carrot and karapincha (positive deviations) and guava leaf, red chillies and betel (negative deviations). Ginger, betel and red chillies gave high blanks and hence the deviations were not surprising. In all the other 14 cases, blanks were in the order of 2 to 10% total optical density reading.

TABLE 1. Cyanide liberation from linamarin by plant material.

Tissue	Name of species	Cyanide liberated (%)	Glucoside remaining (%)
Turmeric rhizome	*Curcuma Longa* L.	0	92
Murunga leaf	*Moringa pterygosperma* Gaertn.	0	105
Katurumurunga leaf	*Sesbania grandiflora* Pers.	64	37
Ginger rhizome	*Zingiber officinale* Rosc.	0	143
Gotukola leaf	*Centella asiatica* L.	0	93
Gotukola leaf	*Hydrocotyle asiatica* Urb.	5	85
Mukunuwenna leaf and stem	*Alternanthera sessilis* R. Br.	100	0
Red onion bulb	*Allium Cepa* L.	0	93
Chillie capsule (green, fresh)	*Capsicum annuum* L.	0	110
Chillie capsule (red, dry)	*Capsicum annuum* L.	0	51
Kankun leaf and stem	*Ipomoea aquatica* Forsc.	95	06
Betel leaf	*Piper Betle* L.	0	69
Karapincha leaf	*Murraya Koenigii* Spreng.	0	122
Carrot tuber	*Daucus Carota* L.	0	164
Coconut endosperm	*Cocos nucifera* L.	83	12
Guava leaf	*Psidium Guajava* L.	0	14
Japan-batu leaf	*Phyllanthus sp.*	0	108

Plant extracts (from 15 g fresh weight) were incubated with linamarin (25 mg) for 24 h. Cyanide liberated was determined after distillation. The glucoside remaining was determined after incubation with linamarase (150 units) for 24 h. In each case appropriate controls (with linamarin omitted) were used to obtain blank values which were subtracted before calculations were made.

After some of the experiments microbial spoilage was evident. The experiments were therefore repeated with sterilized apparatus. The negative results obtained above were essentially the same ; but no release of cyanide was obtained with coconut endosperm and katurumurunga leaf (Table 2). The cyanide liberating activity of kankun and mukunuwenna was destroyed by boiling for 10 min and deactivated to a considerable extent in semi-cooked preparations such as "mallung".

TABLE 2. Cyanide liberation from linamarin.

Material	Cyanide liberated (mg)			
	Boiled (10 min)	Semi-cooked*	uncooked	blank†
Mukunuwenna leaf	0.11	0.51	4.07	0.23
Kankun leaf	0.00	0.04	3.98	0.00
Katurumurunga leaf	0.00	0.13	0.07	0.16
Coconut endosperm	0.00	0.00	0.20	0.03

Plant material extracts (from 5g fresh weight) incubated with linamarin (40 mg) for 24 h

* Cooking for about 3 min as in the preparation of "mallung".

† Control value for plant material incubated and distilled in the absence of linamarin.

3.4. Effect of coliform bacteria

As it appeared possible that in at least some cases the release of cyanide from linamarin might be due to microbial action, coliform bacteria were tested for their ability to hydrolyse linamarin. Tests showed that none of the 7 coliform types tested were able to release a significant amount of cyanide from linamarin (Table 3).

TABLE 3. Cyanide liberation from linamarin by coliform bacteria.

Culture	Coliform type (I M V_i C)	Cyanide released (µg/ml) 0 h	4 h	24 h	Glucoside remaining (µg/ml as cyanide) 0 h	4 h	24 h
A	+ + — —	0	0.0	1.5	49.5	50.0	54.0
D	+ + + —	0	0.0	0.5	47.0	49.0	50.0
F	— + — +	0	0.0	0.5	50.0	52.0	47.5
J	+ + + +	0	0.0	1.0	51.5	48.0	51.5
L	— + + +	0	0.0	0.0	51.0	47.5	47.5
M	— — — +	0	0.5	2.0	50.0	50.0	50.0
O	— — + +	0	0.0	1.0	49.0	46.0	47.5

Concentration of linamarin added : 48.5 µg/ml as cyanide. Standard deviation for glucoside estimation: ± 3 µg/ml as cyanide. Values obtained for cyanide release are not significant.

3.5. Further studies with ginger

Repeat experiments with several samples of ginger showed that incubation with linamarin released, if at all, only small amounts of cyanide. Similar results were obtained with purified ginger, proteins and with different protein fractions isolated from ginger. In fact, ginger proteins inhibit the linamarase-linamarin reaction slightly. No activity was obtained with ginger essences.

However, incubation with boiled manioc led to the release of cyanide in the case of some ginger samples ; this active principle was heat labile. Another ginger sample gave no release. The conflicting results were rather puzzling, especially as in all cases fresh ginger samples were used and therefore there was little chance of the loss of an active principle. It is, however, likely that the divergent results obtained were due to differences in varieties of ginger used. In addition, a sample which released cyanide from boiled manioc did not release cyanide from linamarin (Table 4).

3.6. Further studies with mukunuwenna

Although mukunuwenna showed very high cyanide releasing activity from linamarin, cyanide release from boiled manioc was very much less and this too only after 24 h (Table 5). Similar results were obtained with kankun. Katurumurunga, however, did not release cyanide from boiled manioc. Results similar to katurumurunga were also obtained in the case of coconut. This reduction in activity was somewhat puzzling and further investigation revealed that the release of cyanide from linamarin by mukunuwenna was non-linear, a distinct lag being observed (Table 6). This activity was not inhibited in the presence of the microbial inhibitor p. hydroxy ethyl benzoate (1000 p.p.m.).

TABLE 4. Cyanide liberation by ginger.

Materials and treatment	Cyanide release (μg)
A. Manioc (1) + Ginger (1) 4 h incubation	821
B. Manioc (1) + Ginger (1) 24 h incubation	2190
C. B followed by linamarase action (Total residual glucoside)	645
D. Manioc (1) : Total cyanide	2674
E. Manioc (1) + boiled ginger (1) 24 h incubation	N.D.*
F. Ginger (1) + linamarin 24 h incubation	13
G. Manioc (2) + Ginger (1) 24 h incubation	975
H. Manioc (2) + Ginger (2) 24 h incubation	N.D.*
I. Manioc (2) : Total cyanide	2129

Ginger (10 g fresh weight) was incubated with boiled manioc (10 g dry weight) or linamarin (20 mg).

Free cyanide in the manioc samples was in the order of 100 μg. Ginger blanks were in the order of 1000 μg; values given above have been corrected for ginger blanks.

* N.D. not detected ; optical density was less than that of blank.

TABLE 5. Cyanide liberation from boiled manioc by leaf extracts.

Plant tissues	Cyanide released (or equivalent O.D) (μg)		
	Control* 4 h incubation	4 h incubation	24 h incubation
Mukunuwenna leaf	26	157	306
Kankun Leaf	28	151	312
Katurumurunga leaf	108	252	167**

Fresh leaf extract (from 10 g fresh weight) was incubated with boiled manioc (10 g dry weight). Free cyanide in boiled manioc was 113 μg. Total potential cyanide was approximately 2500 μg (Most of this can be recovered by manioc linamarase).

* Control : Plant material incubated and distilled in absence of manioc.

** The low value may be due to some cyanide binding by cyanide utilizing reactions, but this is not important as the cyanide liberated is in any case very low.

TABLE 6. Cyanide release from linamarin by mukunuwenna extract.

Experiment	Time of incubation (h)	Cyanide liberated (μg)
Experiment A	2	0
	4	75
	6	150
	16	1116
	24	1344
Experiment B	22	1150
	22 + Microbial inhibitor *	1233

Linamarin (approximately 15 mg) was incubated with mukunuwenna extract (from 5 g fresh weight). Total volume of reaction mixture was 100 ml (0.02 M with respect to citrate buffer).

* Inhibitor, p. hydroxy ethyl benzoate (1000 p.p.m.)

3.7. Further studies with guava leaf

Results in Table 1 show that the recovery of linamarin from an incubation mixture with guava leaf was only 14%. This could have been due to : (1) binding of HCN formed and (2) inhibition of linamarase used to estimate the residual glucosides. Addition of more linamarase and an increase of incubation time resulted in the release of more cyanide. This showed that the effect was most likely due to an inhibition of linamarase ; the enzyme was inhibited to at least 90% by an extract from 15 g of guava leaf.

This was further confirmed by time-course studies on the effect of guava extract on the linamarin-linamarase reaction (Table 7). These studies showed that guava leaf contained a potent inhibitor of linamarase. This factor was both heat stable and dialysable. A similar inhibition was observed when boiled manioc was used as a source of linamarin (Table 8).

TABLE 7. Inhibition of linamarase action on linamarin by guava extract.

Conditions	Cyanide liberated (μg)					
	Incubation time 0.5 h	1 h	2 h	4 h	6 h	18 h
(i) Guava extract omitted	1240	1790				
(ii) Guava extract		32	60	180	240	540
(iii) Guava extract dialysate		672				

Guava leaf extract (from 10 g) was incubated with linamarin (18 mg) and linamarase (140 units). Total volume of reaction mixture was 100 ml, 0.04 M with respect to citrate buffer (pH 5.0).

TABLE 8. Inhibition of cyanide liberation from boiled manioc.

Materials	Cyanide liberated (μg)
Boiled manioc	84
Boiled manioc, linamarase	1596
Boiled manioc, linamarase, guava extract	0

Boiled manioc (10 g dry weight) was incubated for 4 h in the above manner. Weight of guava leaf used was 10 g (fresh weight). Linamarase activity: 140 units.

4. Discussion

Studies comparing the relative efficiency of acid and enzymic hydrolysis of linamarin have established that the latter method is superior. However, the method of acid hydrolysis at low acid concentrations for an increased period of time warrants further investigation. On comparison of the results of one such technique,[9] that of Rajaguru, with the method used in this study, it was found that enzymic hydrolysis gives values 5 to 10% higher. However, as $AgNO_3$ (which was used in the acid hydrolysis studies) overestimates cyanide by 8 to 14% [12,11] it appears that the relative efficiency of this method of acid hydrolysis is in the region of 80 to 85%.

The nature of liberation of cyanide from linamarin by plant tissues has proved to be somewhat complex. Heat labile factors in kankun and mukunuwenna can bring about this liberation, possibly by a mechanism quite distinct from the linamarase reaction. The latter is suggested by : (1) the lag in cyanide liberation and (2) liberation of very little cyanide from boiled manioc. The second observation suggests considerable inhibition of the cyanide liberating process by manioc substrate ; such levels of inhibition are not shown by manioc linamarase in the presence of manioc substrate.

The effect of ginger is yet more complex. Once again these studies show that the cyanide liberating factor is not a linamarase. It appears that ginger provides a heat labile factor that helps in cyanide liberation. The studies of Kodagoda *et al.*[3] suggest that ginger could be providing an activator to the deactivated manioc linamarase ; the results of this study are consistent with this suggestion. Alternatively, it is possible that the factor produced by ginger is an enzyme whose action is dependent on a minimum level of some unknown cofactor that could be present in either or both manioc or ginger. This alternative would explain the lack of liberation of cyanide from purified linamarin and the observation that some samples of ginger did not liberate cyanide from boiled manioc.

The inhibition of linamarase activity by guava leaf extracts is of significance because these extracts are used as an antidote for manioc poisoning in rural Sri Lanka. Although several extracts used in this study inhibit linamarase activity, none of them

is as effective as guava leaf. This potent inhibitor is a dialysable, heat stable molecule; it is interesting to note that gluconolactone is also an effective inhibitor of manioc linamarase.[11]

5. Conclusion

Extracts of some plant tissues can hydrolyse linamarin but the factors responsible are not the same as linamarase. It is difficult to extrapolate these results to obtain information on the effect of these materials on ingested linamarin, as the cyanide liberating process is very likely to involve an interplay of activators and inhibitors of enzymes superimposed on the complex physiological changes that occur in the digestive system. Further work is needed to determine the exact mechanism of the cyanide liberating processes. This study shows that plant tissue extracts can liberate cyanide from cyanogenic glucosides and, therefore, should serve as a deterrent to the consumption of manioc with raw or semi-cooked plant material.

Acknowledgements

The authors thank Miss N. T. Amerasinghe and Miss R. Kandage for technical assistance, and Mrs. I. Bandara and Miss D. Obadage for secretarial assistance.

References

1. Cerighelli, R. (1955) *In Cultures tropicales* I. Plantes vivirieres (Nouvelle Encycl. Agr., Paris, 1955) p. 367.
   Ref. quoted in Jones, W. O. (1959) *Manioc in Africa*. Stanford, California : Stanford Univ. Press.
2. Jansz, E. R. & Nethsingha, C. (1973) *J. Natn. Sci. Coun. Sri Lanka* **1** (2): 83-96.
3. Kodagoda, N., Markus, V. & Ambalavanar, S. (1973) *Proc. Ceylon Ass. Advmt Sci.* 29 (1): 38.
4. Nartey, F. (1968) *Phytochem.* **7** : 1307-1312.
5. Nestel, B. & Macintyre, R., *eds.* (1973) *In Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England,* 29-30 *January* 1973, pp. 159-162. Ottawa : International Development Research Centre. (IDRC-010e).
6. Nicholls, L. (1951) *In Tropical nutrition and dietetics,* 3rd edn. p. 381. London : Bailliere, Tindall & Cox.
7. Pieris, N., Jansz, E. R. & Kandage, R. (1974) *J. Natn. Sci. Coun. Sri Lanka* **2** (1) : 67 — 76.
8. Pieris, N., Premadasa, G. G. & Jansz, E. R. (1973) *J. Natn. Sci. Coun. Sri Lanka.* **1** (2): 207-210.
9. Rajaguru, A. S. B. (1973) *Private communication.*
10. Wood, T. (1965) *J. Sci. Fd Agric.* **16** : 300-305.
11. Wood, T. (1966) *J. Sci. Fd Agric.* **17** : 85-90.
12. Zitnak, A. (1973) *In Chronic cassava toxicity : proceedings of an interdisciplinary workshop, London, England,* 29-30 *January* 1973, pp. 89-95. Ottawa : International Development Research Centre. (IDRC-010e).

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 67—76.

Cyanogenic Glucoside Content of Manioc

I. An Enzymic Method of Determination Applied to Processed Manioc

NIRMALA PIERIS,* E. R. JANSZ AND RADHA KANDAGE

Ceylon Institute of Scientific and Industrial Research (CISIR), P.O. Box 787, Colombo 7, Sri Lanka

(Paper accepted: 2 May 1974)

Abstract : A method for the determination of the total cyanide content of manioc products is described. Exogenous linamarase has been used to hydrolyse the linamarin in the plant material. Enzyme activity, incubation time and volume of distillate have been varied such that maximum recovery of total cyanide was obtained. Recovery of added HCN and linamarin from manioc substrate was found to be satisfactory. The method was applied to determine the total cyanide content of boiled manioc, manioc flour and manioc starch. Raw manioc on boiling was found to lose $\frac{3}{4}$ to $\frac{1}{2}$ of its total cyanide. Steeping with leaves prior to boiling did not alter these values significantly. It was found that while manioc starch contained only small quantities of total cyanide, manioc flour unless specially processed to reduce cyanide content, contained 50 to 250 p.p.m. total cyanide.

1. Introduction

Manioc, *Manihot esculenta* Crantz, contains compounds from which cyanide may be liberated, namely the cyanogenic glucosides linamarin and lotaustralin. In addition, it also has small amounts of free cyanide (HCN) and probably contains cyanohydrins. Although most methods of processing to a great extent eliminate free cyanide, it is clear that unless special precautions are taken, bound cyanide (mainly the cyanogenic glucosides) persists.[4,10,13] The extent of cyanogenic glucoside content remaining in processed manioc has been subject to controversy.[7] This has been mainly due to the accumulation of misleading data in the literature due to : (1) poor sampling[14] and (2) use of sub-optimum conditions for hydrolysis of linamarin.[7] Much of the literature on the topic is therefore of dubious value and it is generally recognized,[3,14] that a fresh set of data, using reliable methods, is an urgent necessity.

This paper presents such a method (previously outlined[10]) where additional linamarase is used to hydrolyse linamarin completely. Although methods with additional linamarase have been used before,[4,5,13] these methods have not been completely satisfactory. Wood[12,13] did not consider all the important parameters concerned with the extent of enzyme hydrolysis and also used unsuitable conditions for recovery of HCN (aspiration in acid conditions). De Bruijn[4,5] used a crude leaf extract for his studies (which necessarily resulted

*This paper forms part of a M.Sc. dissertation (University of Sri Lanka, Colombo Campus) of Nirmala Pieris.

in high HCN blanks) and also used the non-specific $AgNO_3$ titration to determine cyanide. Furthermore, he did not pay attention to some variables that have been considered in this study.

2. Experimental

2.1. Materials

Tubers of different varieties of manioc available in the local market were used. Manioc flour was prepared by cutting the edible part into chips followed by drying in a forced-draft oven at 55 to 60°C. The dried chips were then finely powdered and sieved (180 mesh). Manioc starch was prepared by a standard wet process[6] using three resuspensions of starch. Boiled manioc used was prepared (unless otherwise specified) by cutting the edible part into approximately 1 in cubes and boiling for about 45 min in an open vessel.

2.2. Sampling

Flour and starch which lend themselves to complete mixing presented no problems. However, as the cyanogenic glucoside content of the tubers varies lengthwise [5,9] and also radially,[4] special precautions had to be adopted in comparative studies of whole manioc. The tuber was quartered and the opposite quarters pooled; this resulted in two samples of equal cyanide content (**3.** Results). The samples were then blended in a Waring blendor until completely homogeneous.

2.3. Assay for total cyanide in samples

Samples of starch, flour, homogenised fresh manioc or homogenised boiled manioc (approximately 10 g dry weight) were incubated in 200 ml of water containing 10 ml of citrate buffer (0.2 M, pH 5.0) and about 150 units (μg/ min) of linamarase for 4 h at room temperature (28 to 30°C). The samples were then distilled; approximately 200 ml of distillate was collected in 50 ml of an aqueous solution of 6.25% Na_2CO_3 or of 1.0% NaOH. The distillate (usually 4 ml) was tested for cyanide by the method of Wood[12] (Picrate method) using a spectrophotometer. The cyanide was estimated quantitatively with the aid of standard curves, taking into account the presence of the appropriate amount of Na_2CO_3 or NaOH used. Gradients obtained were .0122 and .0105 (optical density/μg) respectively. Collection in Na_2CO_3 solution was superior to collection in NaOH as use of the latter resulted in a diminution of the colour obtained. Hence Na_2CO_3 was used in nearly all the experiments presented in this paper.

2.4. Preparation of linamarin and linamarase

Both linamarin and linamarase were prepared by the method of Wood.[13] These preparations when distilled separately produced no colouration with the picric acid test.

2.5. Assay of linamarase

The method of Wood[13] was used except that the reactions were carried out in a syringe (5 ml) such that there was no air space above the liquid. The reaction mixture contained a suitable volume of linamarase extract and excess linamarin (approximately 2.5 mg) in 5 ml which was 0.08 M with respect to citrate buffer (pH 5.0). The reaction was carried out at room temperature. Aliquots (1 ml) were carefully introduced at 3 or 5 min intervals into the detecting mixture and cyanide determined by the method of Wood.[13] Enzyme activity was calculated using the linear part of the reaction curve. A standard curve for equimolar amounts of cyanide and glucose was used in the calculation. The curve is biphasic where r = .014 from 5 μg to 15 μg cyanide and .021 from 15 μg to 80 μg cyanide.

2.6. Assay of linamarin

Two methods were used: (1) the distillation method (after incubation with excess linamarase for 20 h) and (2) direct determination in a syringe using excess linamarase (300 units) and about 1 mg linamarin. Readings were taken at 2 h intervals until no further cyanide was liberated. Other details were the same as in the assay for linamarase.

3. Results

3.1. Preliminary studies

Variation of the quantity of enzyme used and incubation time (Tables 1 and 2) showed that maximum cyanide recovery could be obtained using the conditions described (**2.** Experimental). Zero time and zero enzyme values in the data are due to free cyanide and possibly residual enzyme activity.

Table 3 shows that the bulk of the cyanide present in the reaction mixture can be collected in the first 125 ml of distillate. However, in practice, 200 ml of distillate was collected. Under these conditions it was found that if KCN is added into the incubation mixture, then HCN could be recovered quantitatively.

TABLE 1. Effect of incubation time on cyanide liberation.

Incubation time (h)	Cyanide liberated (p.p.m.)	
	Sample A	Sample B
—	11	—
0.5	29	26
1.0	36	32
1.5	50	—
2.0	56	48
4.0	55	48

Boiled manioc was incubated with 136 units of linamarase ; for further details see **2.** Experimental.

TABLE 2. Effect of enzyme activity on cyanide liberation.

Linamarase activity (μg/min)	Cyanide liberated (p.p.m.)
—	7
68	65
136	67
204	67

In all cases boiled manioc was incubated for 4 h ; for further details see 2. Experimental.

TABLE 3. Effect of volume of distillate on cyanide recovery.

Experiment	Volume of distillate (ml)	Cyanide recovered (p.p.m.)
1	25	69
	50	69
	75	76
2	100	77
	125	84
	150	83
3	175	86
	200	85
	225	88

3.2. Recovery of linamarin

Having separately determined the optimum conditions for liberation of HCN from bound cyanide and its recovery, it was decided to confirm this method by testing the recovery of HCN from linamarin. The results obtained are in Table 4 which shows apparently high values. Further experiments very often gave recoveries about 10% higher than expected. It is believed that this is due to an error in the estimation of linamarin (Table 5).

TABLE 4. Recovery of linamarin added to boiled manioc.

Linamarin added (as μg cyanide)	% recovery
177	104
354	107
531	98
708	119
885	114
1092	117

Linamarin was added into a sample of boiled manioc containing 600 to 700 μg total potential cyanide and the cyanide assay carried out as described in **2.** Experimental. Linamarin concentrations were estimated by the syringe method.

TABLE 5. Linamarin estimation by different methods.

Linamarin sample	Cyanide content (mg/ml)	
	Syringe method	Distillation method
1	5.3 ± 0.3	5.9
2	4.3 ± 0.3	4.9
3	1.4 ± 0.1	1.6

3.3. Sampling

Sampling was done as described (**2.** Experimental). The two samples obtained from each tuber were treated separately and the total cyanide content determined. Results showed that the cyanide content of the two samples were almost identical (Table 6) and as a result this method was used in all studies conducted with whole manioc tubers.

TABLE 6. Sampling of whole manioc.

Experiment no.	Total cyanide (p.p.m. fresh wt)	
	Sample A	Sample B
1	122	124
2	51	50
3	50	50

Tubers were divided into two parts as described in **2.** Experimental and assayed after homogenisation with crushed ice.

3.4. Total cyanide content of raw manioc

After several preliminary experiments it was found that the highest yield of total cyanide was obtained when the material was homogenised with crushed ice. The value obtained was slightly higher than when the tissue was homogenised in 0. 1N H_2SO_4 to deactivate the endogenous linamarase, and considerably higher than when the manioc cubes were warmed in the same strength of acid. Undoubtedly, even homogenisation in ice results in some (very small) loss of cyanide but results obtained by this method were highly reproducible.

3.5. Total cyanide content of boiled manioc

On application of the assay and sampling techniques to test the effect of normal cooking procedures on total cyanide content of manioc, it was found that boiling reduced the concentration of total cyanide to $\frac{1}{3}$ to $\frac{1}{2}$ of the value of raw manioc (Table 7). The percentage decrease varied from sample to sample. The total cyanide content of boiled manioc was found to vary between 11 and 180 p. p. m. (on fresh weight).

It was found that the size to which the material is reduced prior to boiling, affects the final amount of total cyanide slightly; work is proceeding on this aspect and also on the effect of opening and closing the lid of the cooking vessel.

It has been recently reported[2] that when chopped raw manioc is steeped with certain vegetables, the cyanide content of the boiled product is reduced. Studies with leaves, however, showed that the total cyanide content of manioc was not significantly affected by this procedure (Table 8).

TABLE 7. Effect of boiling on total cyanide content.

Sample	Total cyanide content (p.p.m. fresh wt.) Raw	Boiled	% remaining after boiling
1	117	46	39
		46	39
		46	39
2	128	66	52
3*	298	97	33

Manioc tubers were divided into two samples (2.2. Sampling); one was assayed raw and the other after boiling.

*This sample was from the branched tree form of manioc, locally termed "rubber manioc".

TABLE 8. Effect of steeping and boiling with leaves.

Leaf use		Total cyanide content (p.p.m. fresh wt)	
Common name	Botanical name	Control	Experimental
Katurumurunga	*Sesbania grandiflora*	55	45
Katurumurunga	*Sesbania grandiflora*	49	49
Katurumurunga	*Sesbania grandiflora*	33	38
Kankun	*Ipomea aquatica*	61	61
Mukunuwenna	*Alternanthera sessilis*	60	56

Manioc, sampled as described above, was steeped with finely sliced leaves for 2 h and boiled. The second sample was boiled in the normal way and used as Control.

3.6. Total cyanide content of manioc flour

This was previously reported in a short communication.[10] The values reported in that study did not take into account the effect of sodium hydroxide on cyanide-picrate reaction and hence have to be corrected by the factor given in **2.** Experimental.

Analysis of manioc flour prepared by the method described here and by more specialized processes[8,11] designed to remove cyanide is shown in Table 9. Clearly, the final total cyanide content of the flour varies considerably (this is mainly dependent on the glucoside content of the raw material). The percentage loss of total cyanide when flour was prepared in this way from manioc has not been calculated in this study as an adequate sampling procedure has still to be worked out. Preliminary studies, however, indicate that losses are small.

The specialized processes[8,11] on the other hand, yield flour of very low total cyanide content.

TABLE 9. Total cyanide content of manioc flour.

Process	Total cyanide content (p.p.m.)
1. As described in 2. Experimental	197
2. As described in 2. Experimental	58†
3. As described in 2. Experimental	240**
4. As described in 2. Experimental	203
5. As described in 2. Experimental	614*
6. Rajaguru method[11]	N.D.
7. Rajaguru method	6
8. JeyaRaj process[8]	8
9. JeyaRaj process	3†
10. JeyaRaj process	10**

* "rubber manioc"
** same raw material
† same raw material
N.D. not detected, less than 2.5 p.p.m.

3.7. Total cyanide content of manioc starch

Three samples of manioc starch prepared by a standard wet process were analysed. The total cyanide content of these samples were 11, 4 and 4 p.p.m. respectively.

3.8. Free cyanide content in processed manioc

In nearly all cases the free cyanide content was low, generally between 0 and 10 p.p.m. Little attention was paid to free cyanide in this study as results in this range of concentration are not easily calculated with the detecting reagent used here ; besides, free cyanide generally forms only a small percentage of the total cyanide in most manioc products.

4. Discussion

The first part of this study was devoted to the determination of the optimum conditions of liberation and isolation of cyanide. It was found that 150 units of linamarase used with an incubation time of 2 h was sufficient to liberate bound cyanide. However, in this study, the incubation time was increased to 4 h as an additional precaution. The liberated cyanide was recovered by steam distillation, 200 ml of distillate being collected. Results showed that further increase of (1) the quantity of enzyme used, (2) incubation time and (3) volume of distillate collected produced no further recovery of cyanide.

Next, the efficiency of recovery of total cyanide was tested. Addition of KCN into the reaction mixture showed that quantitative recovery was possible. However, this is not the best test of recovery as the main product of enzyme hydrolysis is keto-cyanohydrins which are in equilibrium with HCN, the position of the equilibrium being very much towards the cyanohydrins. Due to this and because keto-cyanohydrins decomposed to give HCN at 85°C, recoveries using linamarin are of more significance. Difficulties in obtaining a quantitative recovery from linamarin appeared to be mainly due to an approximately 10% underestimation of the linamarin as determined by the syringe method ; the reasons for this are not clearly understood. Furthermore, the mean value obtained by this method has a standard deviation of 5 to 6%. Taking these factors into account, it appears that a quantitative recovery of linamarin has been achieved. In addition, there does not appear to be a way by which either linamarin or one of its products could be converted to a volatile compound that would give a more intense picrate colour reaction than cyanide.

Manioc does not appear to contain any other volatile compound that will produce a colour reaction with picrate. This is deduced by the facts that firstly, those samples with no free cyanide do not produce any colouration in the absence of added linamarase (i.e. all colour produced is enzyme dependent) and secondly, flour processed to be free of total cyanide has given optical densities as low as 0.005 (where the normal optical densities are in the range of 0.10 to 0.60).

It seemed possible that some volatile compound might enhance the colour formed by picric acid and cyanide (especially at high cyanide concentrations) and therefore lead to spurious results. This appears not to be the case as : (1) drastic variation of sample size does not alter the quantity of cyanide liberated /g of sample, (2) the absorption spectrum of the cyanide-picrate colour reaction of the distillate is identical to that formed by the same quantity of pure HCN and (3) the early studies (using aspiration) showed that estimation of cyanide liberated by the picrate method and 'Alridges method' gave the same result (<2% error). These points together with the high reproducibility of the results obtained in this study underline the validity of the method. Furthermore, a simple technique of sampling whole manioc such that any two given treatments may be reliably compared has been devised.

Applications of the technique to boiled manioc showed that $\frac{1}{3}$ to $\frac{1}{2}$ of the glucoside still remains after the standard cooking procedure. In some instances (18 out of 26) the amount remaining is not sufficient to produce a lethal dose of cyanide in a meal (for the average healthy adult) even if all the glucoside is hydrolysed in the alimentary canal. In other cases (8 out of 26), however, the quantity of total cyanide exceeds 40 mg/250 g dry weight and in these instances complete hydrolysis in the alimentary canal could produce a lethal effect. Fortunately, it appears probable that the extent of glucoside hydrolysis after consumption is relatively small ; this may explain why a meal of manioc is rarely fatal.

These studies have also shown that steeping with vegetable leaves, etc. (as recommended recently to the public[2]) does not significantly affect total cyanide concentration. This is to be expected as the manioc glucoside and the leaf enzyme (if present) have no chance of interacting. Similar results have been obtained by another independent study.[11]

Studies on manioc have clearly shown the need for well organised processing of manioc products. Dependable methods[8,11] are now available (this paper presents the results) that reduce cyanide level from an alarming level of 200 p.p.m. to a relatively harmless level of 0-10 p.p.m.

Acknowledgements

The authors thank Mr. S. F. Laurentius, Deputy Director (Research), CISIR and Mr. E. E. JeyaRaj, Head, Industrial Microbiology Section, CISIR for encouragement, Mr. D. J. Abeyratne for technical assistance, and Mrs. I. Bandara and Miss D. Obadage for secretarial assistance.

References

1. ALRIDGE, W. N. (1944) *Analyst* **69** : 262-263.
2. CO-OPERATIVE WHOLESALE ESTABLISHMENT. Research & Development Division. (n.d.) *Manioc as food.* [4p]. Colombo : Sri Lanka Government Press. (Research work supervised by N. N. de Silva. Leaflet of 4p.; text : 2p. in Sinhala, 1p. in English).
3. COURSEY, D. G. (1973) *In Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England,* 29-30 *January* 1973, pp. 27-36. Ottawa : International Development Research Centre. (IDRC-010e).
4. DE BRUIJN, G. H. (1971) *Etude du caractare cyanogenetique du manioc* (*Manihot esculenta* Crantz) : *A study on the cyanogenetic character of cassava,* pp. 71, 13. Wageningen : H. Veenman & Zonen N. V. (Mededelingen Landbouwhogeschool Wageningen. Nederland 71-13) (1971).
5. DE BRUIJN, G. H. (1973) *In Chronic cassava toxicity : proceedings of an interdisciplinary workshop, London, England,* 29-30 *January* 1973, pp. 43-48. Ottawa : International Development Research Centre. (IDRC - 010e).
6. F. A. O. (1971) *Agric. Ser. Bull.* (8) : 15-44.
7. JANSZ, E. R., & NETHSINGHA, C. (1973) *J. Natn. Sci. Coun. Sri Lanka.* **1** (2) : 83-96.
8. JEYARAJ, E. E., JANSZ, E. R. & ABEYRATNE, D. J. (1974) *Unpublished results.*
9. JOACHIM, A. W. R. & PANDITTASEKERE, D. G. (1944) *Trop. Agric.* **100** : 150-163.
10. PIERIS, N., PREMADASA, G. G. & JANSZ, E. R. (1973) *J. Natn. Sci. Coun. Sri Lanka* **1** (2) : 207-210.
11. RAJAGURU, A. S. B. (1973) *Proc. Ceylon Ass.Advmt Sci.* **29** (1) : 70-71.
12. WOOD, T. (1965) *J. Sci. Fd Agric.* **16** : 300-305.
13. WOOD, T. (1966) *J. Sci. Fd Agric.* **17** : 85-90.
14. ZITNAK, A. (1973) *In Chronic cassava toxicity : proceedings of an interdisciplinary workshop, London, England,* 29-30 *January* 1973, pp. 89-96. Ottawa : International Development Research Centre. (IDRC-010e).

J. Natn. Sci. Coun. Sri Lanka 1974 **2**(1) : 77-86.

Hot Smoke Fish Curing

M. CAURIE, TUNG-CHING LEE, M. SALOMON AND C. O. CHICHESTER
Department of Food and Resource Chemistry,
University of Rhode Island, Kingston, Rhode Island 02881, *U. S. A.*

(*Paper accepted :* 21 *May* 1974)

Abstract : This review discusses the use of direct wood fire as a source of energy and smoke to dry and preserve fish in the developing countries. It covers various treatment and handling methods as well as the physical and chemical nature of the smoke. It points out that the present traditional methods are inefficient and wasteful of energy and smoke and cites attempts made to improve on them.

It discusses the dynamic equilibrium that exists between the particulate and gaseous smoke fractions. The compounds in the gaseous fraction are stated to be more directly involved in the development of colour, odour and flavour while those of the particulate fraction serve as a reservoir. Phenolic compounds are found to be particularly active in the smoking process.

The nutritional and health effects of the use of high temperatures in the smoking process are also discussed.

1. Introduction

The use of direct wood fire as a source of energy to dry fish dates back into history. There was certainly no fire without smoke ; as the fish dried it also became smoked. It is believed that as the special organoleptic and preservative properties of the smoke-dried fish became evident, the fish was deliberately smoked. In tropical Africa and Asia, fish smoking as a means of fish preservation is extensively practised.

Though smoking has been practised over many centuries in various parts of the world, it has been done empirically and it is only recently that the mechanism of the process is being elucidated and the advantages and limitations of current methods being appraised. This report discusses some of the current methods and ideas relating to fish smoking.

2. Traditional methods of fish smoking

Methods in use vary with local customs, species of fish and product keeping-time desired. These include hot smoking, smoke drying, combined smoke/sun drying, boiling and smoke/sun drying.[11]

2.1. Initial handling

The fish to be smoked are usually washed descaled but may or may not be gutted. They may also be brined or left unbrined. Where the fish are brined, they may either be immersed in brine (70 to 95% solution) or packed in dry salt for periods

ranging from 5 min to 12 h depending on the size of fish, fat content and local taste. After this treatment, the flesh of the fish may reach a salt concentration of up to 3%. When the fish are heavily salted, as when they are packed in dry salt, they are usually desalted by immersion in fresh water for periods of up to 24 h.

Whether brined or merely washed in water, excess surface moisture on the fish is evaporated prior to the actual smoke treatment by exposing either to the atmosphere or predrying for a short period at a low temperature (30° C) in an oven. This surface evaporation may last from 30 min to 4 h and it results in a firm, shiny surface especially when the fish have been brined in 70 to 80% salt solution.

2.2. Smoke curing units and processes

In many developing countries, the fish are smoked on home-made wooden slats placed on wooden supports. A smouldering type fire is lit directly below the rack and the fish are cooked, dried and smoked for several days. In other methods, the fish are laid or hung on metal grills over shallow, open-top, circular, earthen or metal structures with fire and smoke generated directly below the grill. Thus in some areas, the fish are cooked and smoked simultaneously, while in others they are cooked prior to exposure to smoke. While lying or hanging on grills or on wooden slats, the fish are normally arranged and turned periodically to obtain a uniform cure. The drying and smoking treatments may last from a few hours to several weeks in some instances.[11] When dried for long periods, the purpose is to reduce the fish to a very low moisture to prolong its keeping qualities.

These traditional smoking structures and procedures, commonly used in developing countries, are highly inefficient and wasteful of energy and smoke. There is, for example, an unrestricted escape of smoke, heat and moisture from the open tops of the grill supports.

Recently, attempts have been made to improve on the design of these traditional smoke units.[11,3] These designs have, to a limited extent, succeeded in increasing the volume of fish cured but have not significantly controlled such important factors in hot smoke fish curing as smoke density, humidity, temperature and air velocity.

In developed areas of Europe and America, the fish are usually heavily salted before smoking. The smoking is usually carried out in ovens with temperature, draught and smoke density controls and the fish are normally smoked lightly at moderate temperatures. In these areas, hot smoke curing of fish for preservation is unimportant due to the availability of freezing and cold storage facilities ; instead smoke is applied for the flavouring it imparts to the fish.

Recent studies have improved our understanding of the factors involved in hot smoke fish curing; this is necessary for future improvements on any primitive traditional techniques. These factors are discussed briefly below.

3. Factors in hot smoke fish curing

3.1. Wood suitable for generating smoke

Generally, resinous wood is not recommended for smoking fish because it imparts an unpleasant flavour to the smoked product. Soft wood is also undesirable as it produces too much soot. Best results are generally obtained with hardwoods.[32] It is, however, recommended that they be tested before they are used as some of them may impart dark colours and bitter taste to the smoked fish. Maize cob,[32] sugar cane pulp and coconut fibre[1] are some of the non-resinous materials used in fish smoking in some developing countries.

Experiments in Canada[25] indicate that white fish with a good flavour may be produced from smoke generated with red maple, red oak, trembling aspen, white ash, balsam poplar and birch. Diamond willow and burr oak gave objectionable flavours ; hickory wood was marginally acceptable.

3.2. Method of smoke generation

Methods for generating smoke vary from place to place. In the United States, three methods are in use[9] — smoke may either be generated by burning dampened sawdust, or by burning dry sawdust continuously, or by the method of friction. In the latter method, smoke is generated by pressing the end grain or hardwood block against a rotating carbide-tipped disk. The commonest method of generating smoke in other parts of the world, however, is to burn hardwood in a smouldering type flame at temperatures which may reach between 682 and 966°C.[40]

3.3. Smoke as a gas/liquid system

When wood or any plant part is burnt, a large number of carbonyl and phenyl compounds are released. The less volatile of these compounds, usually the large molecular weight compounds, upon mixing with colder air, condense into visible light scattering liquid smoke particles while the more volatile fraction remains in the vapour state. There exists, therefore, minute light scattering particles suspended in a medium of air and invincible vapours which together constitute a gas/liquid partition system.[13,14]

3.4. Composition of wood smoke

The composition of wood smoke is highly complex. It depends on the type of wood, type of smoke generator, moisture content of the wood, temperature of combustion and on air supply. Acids, alcohols, carbonyls and many other neutral compounds have been identified as constituents of smoke by various authors.[12,17,30,34,8]

3.5. Distribution of smoke in a closed chamber

The disperse phase of wood smoke has a relatively large surface area compared to its volume and in such a system equilibrium between the particle and vapour phases is expected to be reached almost instantaneously.[14] This means that, in a fixed volume of smoke, the vapour absorbed by the fish tissue is replaced almost instantaneously from the particle phase. In practice, however, it appears that the attainment of equilibrium is not so fast and a non-uniform distribution of carbonyl and phenol compounds has been shown[36] to exist in smoking chambers. This non-uniform distribution does not only occur in the vertical cross section but in various sections of the chamber as well. This distribution pattern results in active and passive areas in the smoking chamber. This problem may be overcome with good controls over airflow, relative humidity, temperature and in the design of the smoking chamber.[36]

3.6. Smoke absorption

Experiments by Foster and Simpson[13] show that smoking does not depend so much on the direct deposition of smoke particles on the fish as on the absorption of the gaseous constituents of the vapour phase of the smoke. This is indicated by their finding that fish cured in vapours which remained after the visible smoke particles had been precipitated electrostatically were indistinguishable in colour, flavour and keeping quality from normally smoked fish.

When smoke vapours are absorbed by the fish tissue in a closed chamber, the gas/liquid partition equilibrium is disturbed. The equilibrium may also be disturbed by admitting air or raising the temperature of the smoking chamber. In either case, the equilibrium is restored by the liquid phase releasing a part of its content into the vapour phase. It is clear from this that during smoking, if the more volatile compounds absorbed by the fish are not replaced from the point of generation, the vapour phase gets enriched with less volatile larger molecular weight compounds. In this connection it has been observed[14] that vapour absorption is greatest when the moisture content of the fish is high and that as it dries there is very little absorption.

3.7. Smoke colour and its uses in foods

Of the constituents of wood smoke, phenols are considered the most important because they are believed to contribute most to the development of flavour and colour and to the general stability of the smoked fish.

The colour of a typically smoked fish is believed to be developed from a non-enzymatic interaction between polyhydric phenolic[43] and carbonyl[47,23] compounds of smoke vapour with collagen of the surface connective tissue. The belief is that not all the phenolic groups in the smoke vapour can interact with collagen. The

phenols involved in the reactions are the large phenolic compounds (> 500 g M W) with sufficient hydroxyl groups to link adjacent collagen sites at several points through hydrogen bonds.

The cross linkages that result from the interaction between protein and phenyl compounds impart to surface tissues great stability to heat, enzymes, water abrasion and to microorganisms. Indeed, when these linkages are formed, very large molecular weight constituents of wood smoke may fail to penetrate the surface:[43,47] A case-hardening effect results, with the sub-surface tissues left unsmoked and susceptible to the effects of heat such as gelatinisation or the breakdown of collagen. This case-hardened layer on the skin often shows final values for smoke constituents 10 to 20 times higher than in the underlying flesh.[4]

3.8. Smoke-flavour and odour

The overall odour and flavour of smoked products are created, according to Daun[7] by : (1) food constituents changed during processing, (2) products of combined food and smoke constituents and (3) uncombined smoke constituents. The phenol fraction of the wood is believed to contribute most to flavour and odour, and the total phenolic content of fish has often been used as an index of the degree of fish smoking.[18,41]

Available evidence indicates that most of the flavouring components of smoke are to be found at or near the surface of the smoked product. By pressing NaOH treated paper against the cut surfaces of sausages and developing the papers chromatographically with 2,6 dichloroquinone-chlorimide, Kurko[21] found indications of phenols only at or near the surface of the smoked product up to 48 h. Shewan[35] found 69 mg% total phenols at the surface, 16.25 mg% in the flesh immediately below the surface and 2.13 mg% at the centre of the fish fillet. Tucker[41] also found phenolic compounds concentrated at the surface.

The phenols guaiacol, 4-methyl guaiacol and syringol (2,6 dimethoxy phenol) have been found[20] to be the major phenols of wood smoke vapour phase. Wasserman[42] found the same phenols to be present in largest concentrations in wood smoke condensate. Taste panelling subsequently showed that the guaiacols had a more smoky-taste while the 2,6 dimethoxy-phenol or syringol had a smoky-odour. Daun[7] similarly observed three gas chromatographic peaks of three unidentified phenolic compounds associated with odour and taste. Like Wasserman[42] he found one of the compounds associated with "smoke cured" odour and the remaining two associated with "smoke cured" taste.

It is clear from this discussion that the efficiency of the smoking process may be determined by the relative contribution of flavour and colour forming compounds. The absorption of these compounds, we have noted, is greatest when the moisture content of the fish is high. This suggests that the fish must not be dried

too quickly to enable the greatest amount of vapour constituents to be absorbed. It also means that the initial smoking temperature must not be too high to cause rapid drying. Clearly, vapour absorption will be favoured by conditions of high humidity and low temperature.

4. The effect of heat on smoked fish

Fish smoking does not only involve exposure to smoke, it also involves drying and baking as well. In developed countries, fish are smoked principally for the colour and flavour the process imparts to fish. In developing areas, on the other hand, fish are smoked principally for preservation. Whatever the aims for smoking fish, they are best served by exposing the fish to some degree of heat treatment which helps the development of both flavour and colour.[46,2]

4.1. Textural problems

The drying, and at times the baking which follows, often causes textural problems in smoked fish. By texture is meant the retention of good microstructure of fibre and fibre substance expressed in terms of softness, juiciness, fibrousness and glutinousness.[6] This is important with respect to reconstitution ability of the dry fish which refers to the extent to which the dried fish fibre returns, on addition of water, to a state indistinguishable from the undried fibre. This depends on the structural properties of collagen or fibre connective tissue.

As the fish dries under excessive heat treatment, the increased concentration of tissue solutes may denature its proteins. Indeed, during heat treatment of fish, Hughes[19] found that there was a degradation of connective tissue or collagen, especially of the skin, to gelatin and other smaller peptide fragments. The fish flesh is held together by connective tissue and the breakdown of the latter should render the fish soft and liable to break upon handling.

Since absorbed smoke constituents may cross link with fish surface tissue proteins under mild heat conditions to form a firm, stable surface,[43] it would appear a good smoking practice to develop this firm outer surface before raising the heat to dry the fish. Mann[32] recommends that during the smoking process more smoke and less heat must be applied in the initial stages.

As a general recommendation the FAO,[11] however, states that the initial pre-drying must be carried out and maintained at 80°C for 2 to 4 h, depending on the size of fish being cured. For the following 2 h, the temperature must be raised to between 90 and 110°C to cook the flesh. After the cooking, it is recommended to return the temperature to 80°C for the rest of the smoke drying process.

4.2. Nutritional losses

Foster and Simpson[13] are of the opinion that the hot smoke curing temperature must be between 32 and 82°C. Temperatures in excess of this either during the initial smoking period or during the later baking process is believed to result in some unfavourable nutritional effects on the smoked product. This conclusion appears to agree with Duckworth and Woodham[10] who found that vegetable proteins heated beyond 82°C suffer a loss in nutritive value; soybean heated to this temperature[31] results in the loss of digestibility of its proteins. Halevy and Guggenheim[16] demonstrated this loss in digestibility by autoclaving wheat gluten/glucose mixture. They found that with such treatment the *in vitro* digestibility of essential amino acids was reduced. However, Yanez *et al.*[45] working with hake fillets observed a negligible change in Net Protein Utilization (NPU) up to 105°C but Net Sulphur Utilization (NSU) suffered some losses at this temperature. Heating at 170°C considerably reduced Nitrogen and Sulphur Utilization—NPU fell from 79 to 41 and NSU from 89 to 60.

Lysine, the most abundant amino acid in fish is also considered[28,31,29] to be the most labile amino acid. A major part of lysine losses undoubtedly results from reaction of the ϵ-amino group with reducing carbohydrates followed by a series of rearrangements and dismutations that lead to brown-coloured polymers and evolution of carbon dioxide. These reactions referred to collectively as non-enzymatic or Maillard reaction are known to form complex linkages which are very resistant to digestive enzymes and are therefore not metabolized.[33]

Greaves *et al.*[15] have reported that even in the absence of the Maillard reaction, heating alone is sufficient to render lysine unavailable. Chen and Issenberg[5] have reported a 44% loss of available lysine after a 10 h exposure of beef to wood smoke; heating alone at 65°C for 10 h, on the other hand, caused a loss of 15% in available lysine. These results indicate that smoke components may account for some of the amino acid losses in smoked products.

The rate at which fish protein may be rendered unavailable may also depend on the moisture content at which the fish are dried. This is indicated by the results of Lea and Hannan[27] who heated a casein/glucose mixture in excess sugar and found a marked loss of amino groups up to a peak value at 70% RH with a minimum loss at the wet and dry extremes. Labuza *et al.*[24] similarly found the rate of browning in a pea-soup mix increasing to a peak value at 70% RH and thereafter falling. Livingston *et al.*[29] have also found the retention of lysine, methionine, cystine, arginine, histidine and aspartic acid during alfalfa dehydration to correlate well with meal moisture and dehydration outlet temperature.

5. Preservative action of wood smoke

Smoke does more than provide desirable flavour and colour to smoked products. It contributes substantially to their preservation by acting as an effective antioxidant, microbiostatic and microbiocidal agent.

Phenols are again reported by Kurko[22] to be the effective antioxidants in smoked products. He found neutral compounds (alcohols, carbonyls), organic acids and bases ineffective as antioxidants. The highest boiling phenols composed of pyrogallol ethers were slightly more effective than lower boiling ones. Foster and Simpson,[13] however, found no difference in antioxidant properties between normally smoked products and those smoked with gases left over after the high boiling phenols, wood resins and tars were removed by electrostatic precipitation. In support of reports[35,41,21] that most smoke constituents are concentrated in the surface tissues, Lea[26] had previously observed very low peroxide values in the surface tissues of smoked bacon, whereas in the unsmoked bacon the peroxide values were very high but decreased to a negligible value only a short way below the surface tissues.

Generally smoke components, for example, formaldehyde, acetic acid and creosote, which concentrate in the surface tissues are not toxic to bacteria, fungi or viruses below a concentration of 1%.[43] Above this concentration, however, they have been found to prevent spore germination and growth of many bacteria, fungi and certainly inhibit the activities of a wide range of viruses.[4]

Since smoke constituents are concentrated in the surface layers, their antimicrobial activities will not affect microorganisms in the sub-surface layers and therefore those microorganisms (especially in the gut) which may survive heat treatment during smoking may grow if the moisture content of the smoked fish is not kept low enough.

6. Wood smoke and carcinogens

In addition to flavouring, colour and antiseptic compounds, wood smoke may contain potent carcinogenic polycylic aromatic hydrocarbons.[39] The generation of these compounds is influenced by the parameters that govern smoke generation which include the type of wood, type of generator, moisture content and degree of comminution of the wood, temperature of combustion and air supply.[40,9]

Burning dampened hardwood sawdust in a limited amount of air, White *et al.*[44] identified the following polycylic aromatic hydrocarbons: anthracene, phenanthrene, pyrene, fluoranthene, triphenylene and 4-methyl-benzo (α) pyrene. The latter substance is considered to be the most carcinogenic and levels greater than 7.2 μg/Kg have been recorded in hot smoked fish.[40]

Tilgner[38] was of the opinion that the formation of 3,4 benzo pyrene in wood smoke may be eliminated by generating smoke at a low temperature (400°C). Indeed, carcinogenic substances have been detected most in smouldering type smokes. Solinck[37] found that smoke condensate and tars decreased with increasing moisture content of the wood used to generate the smoke. Indeed, to the extent that moisture content affects the smoke temperature it could be expected to affect its composition and yield as well.

7. Conclusion

From the smoke curing mechanism just discussed, it is apparent that the most important single factor is temperature control within the smoking chamber. For effective smoking, the temperature of the smoking chamber must be initially kept below 80°C to keep the fish at a desired moisture content long enough to absorb the maximum amount of vapour compounds necessary for the development of texture, colour and odour before raising the temperature to cook and dry the fish. The control of temperature at the point of smoke generation to a low level (<400°C) eliminates carcinogenic compounds from the vapour phase.

Most traditional methods of fish smoking characteristically lack temperature control in the smoking chamber and at the point of smoke generation. Furthermore, the exposure of the fish to smoke fumes is often preceded by excessive drying which limits vapour absorption. These limitations in the smoking technology, aside from producing products of uncertain and often poor quality, may also produce potentially carcinogenic products. Any significant improvement in the existing traditional technology will therefore depend on the control of temperature at various stages in the smoking process.

References

1. Adjetey, J. N. N. (1962) *Fish Res. Rep.* (Accra) **1**(1): 8-11.
2. Aziz, S. A. & Hussain, A. G. (1968) *Agric. Pakistan* **19**: 299,
3. Berg, I. I. (1971) *Smoke houses and the smoke curing of fish*, 43 p. Olympia, Washington : Washington State Department of Fisheries.
4. Borgstrom, G. (1968) *In Principles of food science, Vol.* 1, *Food technology*. London: Collier - Macmillan.
5. Chen, Lan-Bo & Issenberg, P. (1972) *J. Agric. Fd Chem.* **20** : 113.
6. Connell, J. J. (1957) *J. Sci. Fd Agric.* **8** : 526-537.
7. Daun, H. (1972) *Lebensmittel - Wiss. Technol.* **5** : 102-105.
8. Doerr, R. C., Wasserman, A. E. & Fiddler, W. (1966) *J. Agric. Fd Chem.* **14**:662-665.
9. Draudt, H. N. (1963) *Fd Technol.* **17** : 1557-1562.
10. Duckworth, J. & Woodham, A. A. (1961) *J. Sci. Fd Agric.* **12** : 5-15.
11. F. A. O. (1970) *FAO Fish. Rep.* (88) : 43.
12. Fiddler, W., Parker, W.E., Wasserman, A.E. & Doerr, R.C. (1967) *J. Agric. Fd Chem.* **15** : 757-761.
13. Foster, W.W. & Simpson, T.H. (1961) *J. Sci. Fd Agric.* **12** : 363-374.
14. Foster, W.W., Simpson, T.H. & Campbell, D. (1961) *J. Sci. Fd Agric.* **12** : 635-644.
15. Greaves, E.O., Morgan, A.F. & Loveen, M.K. (1938) *J. Nutr.* **16** : 115-128.

16. Halevy, S. & Guggenheim, K. (1953) *Arch. Biochem. Biophys.* **44** : 211-217.
17. Hamid, H.A. & Saffle, R.L. (1965) *J. Fd Sci.* **30** : 697-701.
18. Hanley, J.W., Draudt, H.N. & Brockmann, M.C. (1955) *Fd Technol.* **9** : 591.
19. Hughes, R.B. (1961) *J. Sci. Fd Agric.* **12** : 475-483.
20. Kernreich, M.R. & Issenberg, P. (1972) *J. Agric. Fd Chem.* **20** : 1109.
21. Kurko, V. (1959) *Myas. Ind. SSSR* **30**(1) : 17-18.
22. Kurko, V. (1959) *Myas. Ind. SSSR* **30**(3) : 19-21.
23. Kurko, V.I. & Schmidt, T.A. (1969) *Interaction of carbonyl and reductone-like smoke components with amino acids* : Proc. European Meeting of Meat Research Workers 15 : 1167-1179; (Summ. III) 99-100.
24. Labuza, T.P., Tannenbaum, S.R. & Karel, M. (1970) *Fd Technol.* **24** : 543.
25. Lantz, A.W. & Vaisey, M. (1970) *J. Fish. Res. Bd Can.* **27** : 1201.
26. Lea, C. H. (1933) *J. Soc. Chem. Ind.* **52** : 57T-63T.
27. Lea, C. H. & Hannan, R. S. (1949) *Biochim. Biophys. Acta* **3** : 313-325.
28. Lea, C. H. & Hannan, R. S. (1950) *Biochim. Biophys. Acta* **5** : 433-454.
29. Livingston, A. L., Allis, M. E. & Kohler, G. O. (1971) *J. Agric. Fd Chem.* **19** : 947-950.
30. Love, S. & Bratzler, L. J. (1966) *J. Fd Sci.* **31** : 218-222.
31. Lyman, C. M., Chang, W. Y. & Couch, J. R. (1953) *J. Nutr.* **49** : 679-690.
32. Mann, I. (1960) *Meat handling in underdeveloped countries-slaughter and preservation*, Chap. 10, pp. 148-152. Rome : FAO.
33. Miller, D. S. (1956) *J. Sci. Fd Agric.* **7** : 337-343.
34. Porter, R.W., Bratzler, L. J. & Pearson, A.M. (1964) *J. Fd Sci.* **30** : 615.
35. Shewan, J.M. (1949) *Chemy Ind.* July : 501-505.
36. Skachkov, V.P. (1968) *Rŷb. Khoz.* **44** : 61.
37. Solinck, V.A. (1958) *In Technology of fish processing*, edited by T. R. Makorova, p. 81. Moscow : Food Publishing House. English translation :- Washington : U.S. Department of Commerce.
38. Tilgner, D.J. (1958) *Fleischwirtschaft* **10** : 751-763.
39. Tilgner, D. J. (1970) *Fd Mf.* **45**(11) : 47-50, 87.
40. Tilgner, D.J. & Daun, H. (1969) *Residue Rev.* **27** : 19.
41. Tucker, I.W. (1942) *J. Ass. Off. Agric. Chem.* **25** : 779-782.
42. Wasserman, A.E. (1966) *J. Fd Sci.* **31** : 1005-1010.
43. White, T. (1957) *J. Sci. Fd Agric.* **8**: 377-385.
44. White, R.H., Howard, J.W. & Barnes, C.J. (1971) *J. Agric. Fd Chem.* **19** : 143-146.
45. Yanez, E., Ballester, D. & Donoso, G. (1970) *J. Sci. Fd Agric.* **21**(8) : 426-428.
46. Ziemba, Z. (1969) *Roczn. Technol. Chem. Zywn.* **15** : 139.
47. Ziemba, Z. (1969) *Roczn. Technol. Chem. Zywn.* **15** : 153.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 87—89.

ලිපිවල සාරාංශ - සිංහල පරිවර්තන

ශ්‍රී ලංකාවේ කෙෂත්‍ර රෝපිත ගෝවා, කැරට් සහ බීට් වල ජීවන කාලය සහ සපුෂ්පකත්වයට ශීත ගබඩාවල කොට තැබීමෙහි ඇති බලපෑම.

සේනානායක, වයි. ඩී. ඒ.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1): 1—11.

ගෝවා, කැරට් සහ බීට් ශාක පහත් උෂ්ණත්වයන් (0.5°C — 1.0°C සහ 7.0°C — 8.5°C) යටතේ වෙනස් කාලපරිච්ඡේදයන් තුල (දින 15 සිට 60 දක්වා) ගබඩා කොට තබා පසුව ඒවා එලිමහනේ රෝපණය කිරීම ඒවායේ සපුෂ්පකත්වයට කෙසේ බලපාන්නේදැයි, නිර්ණය කිරීම පිණිස, පරීක්ෂණයක් එම ශාක, පසුව ශ්‍රී ලංකාවේ වෙනස් උස් ප්‍රමාණයන් සහිත (කුන්ඩසාලේ මීටර් 450 සහ නුවරඑළියේ මීටර් 1,850) ස්ථාන දෙකක රෝපණය කිරීම මගින් පවත්වා ඇත.

0.5° සිට 1.0°C දක්වා දින 10 ක් ගබඩා කර තිබුණු සියලුම ගෝවා පැල නුවරඑළියේ රෝපණය කල විට සපුෂ්පකවූ බව ප්‍රතිඵල වලින් පෙනී යයි. කුන්ඩසාලේ සපුෂ්පක වූයේ උපරිම වශයෙන් 57.14% කි. ඒ සමානම උෂ්ණත්වයක දින 50 ක් ගබඩා කර තිබූ කැරට් කුන්ඩසාලේ වැවූ විට ඉතාම හොඳ ප්‍රතිඵල (18% සපුෂ්පක වීමක්) ලැබුණි. ශාක වල ජීවන කාලය, යම් ප්‍රදේශයක එලිමහනේ රෝපණය කිරීමෙන් පසු එම ප්‍රදේශයට ලැබුණු වර්ෂාපතනයට සම්බන්ධ විය. නුවරඑළියේ පහත් මධ්‍යන්‍ය උෂ්ණත්වය ගෝවා වල සපුෂ්පකත්වය වැඩි දියුණු කල අතර, එහි සාමාන්‍ය පුෂ්ප මංජරියන් වර්ධනය කළේය. එම මධ්‍යන්‍ය උෂ්ණත්වයම කැරට් වල සපුෂ්පකත්වය මර්ධනය කළේය. කුන්ඩසාලේ උස් මධ්‍යන්‍ය උෂ්ණත්වය කැරට් වල සපුෂ්පකත්වය වැඩි දියුණු කළ අතර, ගෝවා වල සපුෂ්පකත්වය අර්ධ වශයෙන් නිශේධ කළේය. ස්වාභාවික පුෂ්ප මංජරියන්ගේ වර්ධනය මර්ධනය කළේය. බීට් මෙම පරීක්ෂණයට ප්‍රතික්‍රියා නොකළේය.

ශ්‍රී ලංකාවේ සූක්ෂම ස්පන්දන අධ්‍යයනයට විශේෂ අවධානය සහිත චුම්භක ගෝලය සහ භූ චුම්භක සූක්ෂම ස්පන්දනයන්.

කන්නන්ගර, එම්. එල්. ටී.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1): 13—34.

මෙම ලිපිය භූ චුම්භක සූක්ෂම ස්පන්දනයන්ට සම්බන්ධව චුම්භක ගෝලයෙහි භෞතියත්වය ඉදිරිපත් කරන අතර, ශ්‍රී ලංකාවේ භූ චුම්භක සූක්ෂම ස්පන්දනයන් පිළිබඳව කර ඇති සහ දැනට කෙරෙමින් පවතින අධ්‍යයනයන්ගේ සැලකිය යුතු ප්‍රතිඵල සාරාංශ කරයි.

අත්‍යවශ්‍යක තෙල්.

II. කුරුඳු වල වාෂ්පශීල තෙල් විශ්ලේෂණය කිරීම සඳහා අධෝරක්ත වර්ණාවලීක්ෂක ක්‍රමය යොදා ගැනීම.

විජේසේකර, ආර්. ඕ. බී. සහ පොන්සේකා, කාන්ති එච්.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 35—49.

කුරුඳු කොළයෙහි, කඳේ පොත්තෙහි සහ මුලේ පොත්තෙහි තෙල්වල රසායනික සංයුතිය මැනදී GLC ක්‍රමයත් යොදා විභාග කොට ඇත. අධෝරක්ත වර්ණාවලීක්ෂක ක්‍රමය අත්‍යාවශ්‍යක තෙල් අධ්‍යයනය කිරීමේදී, ප්‍රධාන වශයෙන් පාවිච්චි කොට ඇත්තේ ගුණාත්මක ශිල්පීය ක්‍රමයක් වශයෙනි. මෙම අධ්‍යයනයේදී අධෝරක්ත වර්ණාවලීක්ෂක ක්‍රමය කුරුඳු තෙල්වල ප්‍රධාන වශයෙන් අඩංගු දෑ ප්‍රමාණාත්මකව දැස්තමේන්තු කිරීමට යොදා ගෙන ඇත. කුරුඳු කොළයෙහි තෙල්වල යූජනෝල්, සිනමැල්ඩිහයිඩ, ඇසිටයිල්-යූජනෝල්, සිනමයිල් ඇසිටේට් සහ බෙන්සයිල් බෙන්සොඒට් ද, කඳේ පොත්තෙහි තෙල්වල සිනමැල්ඩිහයිඩ, යූජනෝල් සහ සිනමයිල් ඇසිටේට් ද, මුලේ පොත්තෙහි තෙල්වල කපුරු, 1 : 8–සිනෙඕල් සහ සිනමැල්ඩිහයිඩ් අඩංගුය. ලබාගන්නා ලද ප්‍රතිඵල GLC ක්‍රමය මගින් ලබාගන්නා ලද ප්‍රතිඵල සමඟ බොහෝ ආසන්න ලෙස එකඟ වේ.

රේඛීය කාරකයක සධාරිත ප්‍රතිලෝම පිළිබඳව.

ඇපාසිංහ, ජී. ඩබ්.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 51—55.

සෘජුකෝණාශ්‍රාකාර ත්‍රාසයක සධාරිත ප්‍රතිලෝමය පිළිබඳ සංකල්පය, අදාල දෛශික අවකාශයන්ගේ ගුණයන් භාවිතයෙන් විදහා දැක්වේ. ඉන්පසු අදාල අවකාශ, අනන්ත විශ්මතයන් සහිත වන ද්‍රව්‍යස්ථාවල එක් අවකාශයක සිට තවත් අවකාශයක් දක්වා වන රේඛීය කාරකයන්ට මෙය ව්‍යාප්ත කොට ඇත.

ලිනමරින් වලින් සයනයිඩ් මුදා හැරීම.

ජැන්ස්, ඊ. ආර්., ජෙයරාජ්, ඊ. ඊ., පීරිස්, නිර්මලා සහ අබේරත්න, ඩී. ජේ.

J. Natn. Sci. Coun. Sri. Lanka 1974 **2** (1) : 57—65.

සයනයිඩ් මුදා හැරීමේ හැකියාව සොයා බැලීමට ශාක ද්‍රව්‍ය කිපයක් පරීක්ෂණයට භාජනය කරන ලදී. මෙම ද්‍රව්‍යයන්ගෙන් දෙකකට පිරිසිදු කරන ලද ලිනමරින් වලින් සයනයිඩ් මුදා ගැනීමට හැකියාව තිබිණි. කෙසේ වුවද, මෙම මුදා ගැනීමේ යාන්ත්‍රණය, මඤ්ඤොක්කා වල ලිනමරේස් වෙන් කොට ගැනීමේ ක්‍රමයට අයමාන වූ බව පෙනී යයි. ඉහුරු වලට, පිරිසිදු කරන ලද ලිනමරින් වලින්, සයනයිඩ් සැලකිය යුතු ප්‍රමාණයක් මුදා හැරිය නොහැකි වුවද සමහර නියැදි තම්බන ලද මඤ්ඤොක්කා වලින් සයනයිඩ් වෙන් කරන බව පෙනී ගොස් ඇත. මෙහිදී වුවද, මෙම ප්‍රතිඵලය මඤ්ඤොක්කා වර්ගීය ලිනමරේස් නිසා සිදුවන බවක් නොපෙනේ. කොලිෆෝම් වලට ලිනමරින් වලින් HCN මුදා හැරිය නොහැක. ප්‍රසිද්ධ මඤ්ඤොක්කා විෂනාශක ඖෂධයක් වන ජේර කොළ ඉස්ම වල ප්‍රබල ලිනමරින් නාශකයක් අඩංගු වේ. ලිනමරින් වල ආම්ලික සහ එන්සයිමීය ජලවිච්ඡේදනය පිළිබඳ වැඩි විස්තර ද වාර්තා කොට ඇත.

මඤ්ඤොක්කා වල අඩංගු සයනොජෙනික් ග්ලූකෝසයිඩ.

1. පිළියෙල කරන ලද මඤ්ඤොක්කා වලට යොදාගනු ලබන නිර්ණය කිරීමේ එන්සයිමීය ක්‍රමයක්.

පිරිස්, නිර්මලා, ජැන්ස්, ඊ. ආර්., සහ කන්දගේ, රාධා.

J. Natn. Sci. Coun. Sri Lanka 1974 2 (1) : 67—76.

මඤ්ඤොක්කා නිෂ්පාදිත වල අඩංගු පූර්ණ සයනයිඩ් ප්‍රමාණය නිර්ණය කිරීමට ක්‍රමයක් විස්තර කොට ඇත. ශාක ද්‍රව්‍යයන්හි ලිනමරින්වල ජලවිච්ඡේදනය කිරීමට බහිර්ජන්‍ය ලිනමරේස් පාවිච්චි කොට ඇත. පූර්ණ සයනයිඩ් උපරිම ප්‍රමාණයක් වෙන් කොට ගත හැකිවනු පිණිස, එන්සයිමීය ක්‍රියා වලියන්, බීජෞෂන කාලයන් සහ දාසුන ප්‍රමාණයන් වෙනස් කොට යොදා ගෙන ඇත. මඤ්ඤොක්කා උපස්ථානුවල ලාක්ෂණය කරන ලද HCN සහ ලිනමරින් වෙන්-කොට ගැනීම සතුටුදායක බව පෙනී ගියේය. මෙම ක්‍රමය තම්බන ලද මඤ්ඤොක්කා, මඤ්ඤොක්කා පිටි සහ මඤ්ඤොක්කා පිෂ්ඨ වල අඩංගු පූර්ණ සයනයිඩ් නිර්ණය කිරීමට යොදා ගත්නා ලදී. අමු මඤ්ඤොක්කා තැම්බීමේදී පූර්ණ සයනයිඩ් වලින් $\frac{1}{3}$ සිට $\frac{1}{2}$ දක්වා ඉවත් වන බව පෙනී ගියේය. තැම්බීමට පෙර කොළ සමග පෙහවීම මෙම අගයන් වල සැලකිය යුතු වෙනසක් නොකළේය. මඤ්ඤොක්කා පිෂ්ඨ වල සයනයිඩ් අඩංගු වූයේ සුළු ප්‍රමාණයක් වන අතර, අඩංගු සයනයිඩ් ප්‍රමාණය අඩු කිරීම සඳහා විශේෂයෙන් පිළියෙළ නොකරන ලද නම්, මඤ්ඤොක්කා පිටි වල කොටස් දශලක්ෂයකට පූර්ණ සයනයිඩ් 50 සිට 250 (p.p.m.) අඩංගු වූ බව පෙනී ගියේය.

උණු දුමෙන් මාලු සැකසීම.

කවුරි, එම්., ලී, ටුං-චිං, සලමොන්, එම්. සහ වයිවෙය්ටර්, සී. ඕ.

J. Natn. Sci. Coun. Sri Lanka 1974 2 (1) : 77—86.

මෙම සමාලෝචනය, සංවර්ධනය වන රටවල මාළු වේලා කල් තබා ගැනීම සඳහා ශක්තිය ත් දුමත් ලබා ගන්නා මාර්ගයක් වශයෙන්, දැව ඉතිරි කිරීම ප්‍රයෝජනයට ගැනීම සාකච්ඡා කරයි. දුම් පිළිබඳ විවිධ පිරියම් ක්‍රම සහ දුම් පරිහරණ ක්‍රම මෙන්ම දුමෙහි භෞතික සහ රසායනික ස්වභාව-යන් මෙහි අඩංගු වේ. දැනට තිබෙන පාරම්පරික ක්‍රම අකාර්යක්ෂම බවද එම ක්‍රම වලින් ශක්තියත් දුමත් අපතේ යන බවද පෙන්වා දෙන මෙම සමාලෝචනය එම ක්‍රම වැඩි දියුණු කිරීමට දරා ඇති ප්‍රයත්න ගැන සඳහන් කරයි.

ආශ්‍රමය හා වායුමය දුම්භාග අතර පවතින ගතික සමතුලිතතාව ගැන මෙහි සාකච්ඡා කෙරේ. වායුමය භාගයේ සංයෝගය මාළුවල පැහැය, ගඳ සහ රසය කෙරෙහි වඩාත් කැලින්ම බලපාන බව සඳහන් කරන අතර ආශ්‍රමය භාගයේ සංයෝග සංචයක් වශයෙන් සේවය කරන බව සඳහන් වේ. දුම්ගැස්සීමේ ක්‍රියා වලියේදී විශේෂයෙන් පීනොලික සංයෝග ක්‍රියාත්මක වන බව සොයා ගෙන ඇත.

දුම් ගැස්සීමේ ක්‍රියා වලියේදී අධික උෂ්ණත්වය යොදා ගැනීම පෝෂ්‍යදායකත්වයට සහ ඔසෆැක්‍රියට බලපාන අයුරු සාකච්ඡා කොට ඇත.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 90—93.

இந்த இதழின் கட்டுரைகளின் சுருக்கங்கள்

இலங்கையில் தோட்டத்தில் நடப்பட்ட கோவா, கறற், பீற் ஆகியவற்றின் பிழைத்தலிலும், பூத்தலிலும் குளிர் சேமிப்பின் தாக்கம்.

சேனநாயக, Y. D. A.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 1—11.

இலங்கையில் இரு வேறுபட்ட ஏற்றங்களைக்கொண்ட இரண்டு இடங்களில் (குண்டசாலை 450m நுவரேலியா 1,850m) நடமுன் வேறுபட்ட காலங்களுக்கு (15 நாட்களிலிருந்து 60 நாட்கள் வரை) குறைந்த வெப்பநிலைகளில் (0.5°—1.0°C; 7.0—8.5°C) சேமித்து வைக்கப்பட்ட கோவா, கறற், பீற் தாவரங்களின் பூத்தலில் குளிர்சேமிப்பின் தாக்கத்தை அறிய நுண்ணாய்வு ஒன்று நடத்தப்பட்டது.

0.5—1.0°C வெப்ப நிலையில் 40 நாட்களுக்கு சேமித்து வைக்கப்பட்ட கோவா தாவரங்கள் அனைத்தும் நுவரேலியாவில் நடப்பட்டபோது பூத்தன என முடிவுகள் காட்டுகின்றன. ஆகக்கூடியதாக 57.14% மட்டுமே குண்டசாலையில் பூத்தன. அதே வெப்பநிலையில் 50 நாட்களுக்குச் சேமித்து வைக்கப்பட்ட கறற் தாவரங்கள் குண்டசாலையில் வளர்க்கப்பட்டபோது மிகச் சிறந்த முடிவுகளைத் (18% பூத்தல்) தந்தன. ஒரு இடத்தில் தாவரங்களின் பிழைப்பானது நடப்பட்டபின் உள்ள மழைவீழ்ச்சியுடன் சம்பந்தப்பட்டதாகும். நுவரேலியாவிலுள்ள குறைவான சராசரி வெப்பநிலை கோவாவின் பூத்தலையும் வழமையான பூந்துணர்களின் விருத்தியையும் அதிகரிக்க உதவிய அதே வேளையில் கறற்றினுடைய பூத்தலைக் குறைவாக்கியது. குண்டசாலையின் கூடிய சராசரி வெப்பநிலை கறற்றினுடைய பூத்தலை அதிகரிக்க உதவியது, கோவாவின் பூத்தலை ஓரளவுக்குத் தடைசெய்ததுடன் வழமையான பூந்துணர் விருத்தியையும் தடைசெய்தது. பீற் தாவரங்கள் இந்த நுண்ணாய்வில் பாவிக்கப்பட்ட மாற்றங்களால் பாதிக்கப்படவில்லை.

இலங்கையில் மைக்குரோத்துடிப்புக்கள் பற்றிய ஆய்வுகளுடன் விசேஷ சம்பந்தமுள்ள காந்தகோள புவிக்காந்தவியல் மைக்குரோத்துடிப்புக்கள்.

கன்னங்கரா, M. L. T.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 13—34.

புவிக்காந்தவியல் மைக்குரோத்துடிப்புகளுடன் தொடர்புள்ள காந்த கோளத்தின் பௌதிகவியலும், இலங்கையில் நடத்தப்பட்ட, இப்போ நடைபெறும் இது சம்பந்தப்பட்ட ஆய்வுகளின் சுருக்கமும் இங்கு தரப்பட்டுள்ளன.

கறுவாவின் எளிதிலாவியாகு தைலங்களின் பகுப்பிற்கு செந்நிறக்கீழ் நுணுக்கலை நிறமாலையியலின் பாவனை

விஜெசேகர, R. O. B. & பொன்சேகா, காந்தி H.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 35—49.

GLC முறைகள் மூலம் கறுவா இலை, மரப்பட்டை, வேர்ப்பட்டை ஆகியவற்றின் இரசாயன அமைப்பு சமீபத்தில் ஆயப்பட்டது. செந்நிறக் கீழ் நுணுக்கலை நிறமாலையியல் essential oils ன் ஆய்வில் முக்கியமாக பண்பறிதற்குரிய தொழில்நுட்பமாகவே பயன்பட்டுள்ளது. இந்த ஆய்வில் செந்நிறக்கீழ் நுணுக்கலை நிறமாலையியல் கறுவாத் தைலங்களின் முக்கிய கூறுகளின் அணுவறிதற்குப் பாவிக்கப்பட்டுள்ளது. இவற்றுள் யூஜினெல், சினமைல் அசிட்டேட்டு, பென்சைல் பென்சோவேட்டு இலைத்தைலத்திலும் ; சினமல்டிகைட்டு ; யூஜினெல், சினமைல் அசிட்டேட்டு மரப்பட்டைத் தைலத்திலும், கற்பூரம், 1 : 8 சினி ஒலா, சினமல்டிகைட்டு வேர்பட்டைத் தைலத்திலும் காணப்பட்டன. இந்த முடிவுகள் GLC மூலம் பெற்ற முடிவுகளுக்கு நெருங்கியனவாக உள்ளன.

நேர்கோட்டுச் செய்கருவியின் பொதுப்படுத்தப்பட்ட நேர்மாற்று பற்றி

எப்பாசிங்க, P. W.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 51—55.

நீள் சதுரத்தாய்த் தொகுதியின் பொதுப்படுத்தப்பட்ட நேர்மாற்று எண்ணக்கரு, சம்பந்தப்பட்ட காவிவெளிகளின் தன்மைகளைக்கொண்டு குணுதி சயப்படுத்தப்படுகிறது. இது இதிலிருந்து காவி வெளிகளின் வெளிகள் முடிவிலாதனவாயிருக்கும் நிலையில் நேர்கோட்டுச் செய்கருவிகளுக்குப் பிரயோகிக்கப்பட்டுள்ளது.

இலினமரீனிலிருந்து சயனைட் விடுவித்தல்

ஜான்ஸ், E. R, ஜெயராஜ், E. E., பீரிஸ், நிர்மலா & அபேரத்ன, D. J.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 57—65.

சயனைட் விடுவிக்கும் ஆற்றலை அறியப் பல தாவரப் பொருட்கள் பரிசோதிக்கப்பட்டன. இவற்றுள் இரண்டு தூய்மைப்படுத்தப்பட்ட இலினமரீனிலிருந்து சயனைட்டை விடுவிக்கக்கூடியனவாயிருந்தன. ஆயினும் விடுவிக்கும் பொறிமுறை மரவள்ளியின் இலினமரேசின் பொறி முறையைவிட வேறுபட்டிருப்பதுபோல் காணப்படுகிறது. தூய்மைப்படுத்தப்பட்ட இலினமரீனிலிருந்து இஞ்சி சயனைட்டை விடுவிக்க முடியாதிருந்தபோதும் சில மாதிரிகளில் அவித்த மரவள்ளியிலிருந்து சயனைட் விடுவிக்கப்பட்டது. இலினமரீனிலிருந்து கொலிபோம்சால் HCN ஐ விடுவிக்கமுடியாது. மரவள்ளி நஞ்சூட்டலுக்குப் பிரபலமான எதிரிடையான கொய்யா இலைச் சாறு இலிமைரேஸின் தாக்கத்தை நிறுத்து கருவிகளைக் கொண்டுள்ளது. இலினமரீனின் அமில, நொதிய நீர்ப்பகுப்புபற்றிய வேறுவிபரங்களும் கொடுக்கப்பட்டுள்ளது.

மரவள்ளியிலுள்ள சயனோஜெனிக் குளுக்கோசைட்

I. பதன்படுத்தப்பட்ட மரவள்ளிக்கு பிரயோகிக்கப்பட்ட ஒரு நொதியமுறை

பீரிஸ், நிர்மலா, ஜான்ஸ், E. R. & கந்தகே, ராதா

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 67—76.

மரவள்ளியாலான பொருட்களிலுள்ள மொத்த சயனைட்டை அளவிடும் முறையொன்று விவரிக்கப்பட்டுள்ளது. தாவரப்பொருளிலுள்ள இலினமரீனை நீர்பகுப்புப்படுத்தப் புறத்தே பிறந்த இலினமரேஸ் பாவிக்கப்பட்டது. மொத்த சயனைட்டின் ஆகக்கூடிய அளவை மீட்டலுக்காக நொதியத் தாக்க வீதம், தாக்கநேரம், காய்ச்சிவடித்த பொருளின் கனம் ஆகியவற்றில் மாற்றங்கள் செய்யப்பட்டன. சேர்க்கப்பட்ட HCN, இலினமரீன் ஆகியவற்றின் மரவள்ளி அடிப்படைப் பொருளிலிருந்தான மீட்சி திருப்திகரமாயிருந்தது. அவித்த மரவள்ளி, மரவள்ளி மாவு, மரவள்ளி மாப்பொருள் ஆகியவற்றின் மொத்த சயனைட்டை அளவிட இந்த முறை கையாளப்பட்டது. பச்சை மரவள்ளி அவிக்கப்படும்போது மொத்த சயனைட்டின் 2/3 இலிருந்து 1/2 பாகம்வரை இழக்கக்காணப்பட்டது. அவிக்கமுன் இலைகளுக்குள் மூடிவைத்தல் இந்த அளவுகளில் மாற்றத்தை ஏற்படுத்தவில்லை. மரவள்ளி மாப்பொருளில் மொத்த சயனைட் குறைவான அளவுகளிலேயே காணப்பட்டது. மரவள்ளி மாவு சயனைட்டைக் குறைக்க விசேஷமாகப் பதன்படுத்தப்படாவிடில் 50 இலிருந்து 250 p.p.m. மொத்த சயனைட்டைக் கொண்டிருக்கக் காணப்பட்டது.

வெப்பமான புகை மூலம் மீன் பதனிடல்

கவுறி, M., லீ, ருங்-சிங், சலொமன், M. & சைச்செஸ்ரர், C. O.

J. Natn. Sci. Coun. Sri Lanka 1974 **2** (1) : 77—86.

அபிவிருத்தியடையும் நாடுகளில் மரத்தை எரிபொருளாகக் கொண்டு பெறப் பட்ட சக்திமூலம் புகையிட்டு மீனைப் பதன்படுத்தல் பற்றி இக்கட்டுரையில் விவாதிக்கப்பட்டுள்ளது. புகையின் பௌதிக, இரசாயன தன்மைகள் பற்றியும் பல்வேறு முறைகள் பற்றியும் கூறப்பட்டுள்ளது. இதுவரை வழக் கிலிருந்துவரும் முறைகள் திறமையற்றதாகவும், சக்தியையும், புகையையும் வீணாக்குவதாகவும் உள்ளன என்பதைச் சுட்டிக்காட்டுவதுடன் இம்முறை களை திறமையுள்ளவையாக்க எடுக்கப்பட்ட முயற்சிகள் பற்றியும் குறிப் பிடப்பட்டுள்ளது.

புகையின் துணிக்கைப்பிரிவுக்கும் வாயுப்பிரிவுக்குமிடையேயுள்ள இயக்க சமநிலை பற்றி விவரிக்கப்பட்டுள்ளது. வாயுப்பிரிவிலுள்ள சேர்வை நிறம், மணம், சுவை ஆகியவற்றோடு நேரடி சம்பந்தமுள்ளதாகவும், துணிக் கைப்பிரிவு ஒரு ஒதுக்கீடாகவும் கருதப்படுகிறது. பீனொலிக் சேர்வைகள் புகையூட்டலில் குறிப்பாக இயங்கக் காணப்படுகின்றன.

உயர் வெப்பநிலைகளில் புகையூட்டல் போஷாக்கு, சுகாதாரம் ஆகிய வற்றில் காட்டும் விளைவுகள் பற்றியும் விவரிக்கப்பட்டுள்ளது.

Journal
of the
National
Science
Council of
Sri Lanka

Instructions to Contributors

Aims and Scope

The purpose of this Journal is to provide a medium for the quick dissemination of the results of research in all fields of Science and Technology. Published material will range from original contributions to review articles describing the state of the art in specific areas, together with short communications.

Manuscripts and all correspondence relating to them should be sent to : The Secretary, Editorial Board, Journal of the National Science Council of Sri Lanka, 47/5 Maitland Place, Colombo 7, Sri Lanka.

Published by The National Science Council of Sri Lanka and Printed at Sri Lanka University Press, Katubedde.

JOURNAL OF THE NATIONAL SCIENCE COUNCIL OF SRI LANKA

INSTRUCTIONS TO CONTRIBUTORS

Manuscripts and all correspondence relating to them should be sent to :

The Secretary, Editorial Board,
Journal of the National Science Council of Sri Lanka,
47/5 Maitland Place, Colombo 7,
SRI LANKA.

EDITORIAL POLICIES

Submission of Papers : Papers are accepted for editorial consideration with the understanding that they have not been published, submitted or accepted for publication elsewhere. Papers accepted for publication may not be published elsewhere in the same form, either in the language of the paper or any other language, without the consent of the Editorial Board.

Research papers, Papers read at Symposia and Reviews may be submitted to the Editorial Board. Research papers should describe original investigations or technological achievements. Reviews should be critical evaluations of existing knowledge in a specialised field. The Journal also accepts Short Communications. They should be submitted if the results are of sufficient importance to merit publication in advance of a full paper.

Languages of Publication : Sinhala, Tamil and English.

Refereeing and Editing : All material submitted is examined by two or more referees prior to publication. Papers are edited to increase clarity and ease of communication. In preparation for the the press, particular attention is paid to grammar and the conventions of the Journal with regard to symbols, illustrations, tables, references and nomenclature.

Manuscripts submitted for editorial consideration can be processed expeditiously if they conform from the outset to the style of the Journal. Authors are thefore advised to follow closely the form described in these instructions.

PRESENTATION OF MANUSCRIPTS

No maximum length of contributions is prescribed but papers should be written clearly and concisely. All unnecessary textual matter, figures and tables must be eliminated. In general, the impersonal form should be used.

Supplementary material of a detailed nature, which is not essential in the printed paper, but may be useful to other workers, may be deposited with the Secretary. Such material will be made available to other scientists on request and a note to this effect should be included in the paper.

The paper should be reasonably subdivided into sections, and if necessary, sub-sections. The following pattern is suggested for Research Papers : (a) Introduction (b) Experimental (c) Results (d) Discussion (e) Conclusions (f) Acknowledgements (g) References. In many cases, two of sections (b), (c) and (d) can be combined. When a separate Discussion is used, it should not recapitulate the results but discuss their significance and relation to the object of the work and to the work of other people. Conclusions should not merely repeat preceding sections.

Special care must be taken in citing references correctly. Responsibility for the accuracy of these rests entirely with the authors. It is the authors' responsibility to obtain written permission to reproduce material which has appeared in another publication.

FORM OF MANUSCRIPTS

Manuscripts should be submitted **in triplicate** - including the original typewritten copy - typed throughout in double spacing on one side of the paper only. Adequate margins should be left (4 cm) with liberal spacing at the top and bottom of each page. The typescript should be free of corrections.

Headings of major sections should be centred and sub-section headings should be placed on the left of the page. The complete set of headings and sub-headings in an article should be numbered following the style adopted in this Journal and the set should reflect the logical development of ideas.

Paging: Each page of the manuscript should be numbered and the name of the first author and page number indicated in the upper right-hand corner of the page.

The *first* page should contain the article title, the name(s) of the author(s) and name and address of the establishment where the work was carried out. In the case of co-authors, respective addresses should be clearly indicated. Female authors should include one of their given names. The title should be concise but informative. The first word of the title should preferably be one useful in indexing and information retrieval. Where a series of related papers is submitted, each individual paper should have the same general heading, followed by a series number and title of the part. Any footnote to the title should be given at the bottom of this page.

The *second* page should contain an abstract (of not more than 250 words) which should be a summary of the entire paper, not of the conclusions alone and intelligible without reference to the paper itself.

The text should begin on page three and each subsequent major section - references, figure legends and table legends should begin on a new sheet.

The *last* page should contain (a) a note as to the number of manuscript pages, figures and tables, (b) proposed running title of less than 42 characters (letters and spaces) and (c) the name and mailing address of the person to whom the proofs should be sent.

Illustrations : All illustrations are considered as figures and each graph, drawing or photograph should be numbered in sequence with Arabic numerals. Authors must submit the original and two duplicates of each figure. Figures should be planned to fit the proportions of the printed page (12 x 17 cm).

Figures must be drawn in Indian ink on plain white paper or board or tracing paper, not larger than 20 x 30 cm. Drawings should be lettered with a lettering set; lettering should be kept large enough to be legible after a reduction of 50 to 60%. If this is not possible, all letters and numerals must be inserted clearly and lightly in blue pencil and not in ink.

Each figure should carry a legend so written that the general meaning of each illustration can be understood without reference to the text. The amount of lettering on a drawing should be reduced as far as possible by transferring it to the legend. Figure legends should be typed on a separate sheet and placed at the end of the manuscript.

Graphs should be plotted on white or blue-lined graph paper or tracing cloth; grid lines that are to be shown in the engraving should be inked in black. The caption of each axis should be lettered parallel to its axis. Each figure should be identified in the margin with authors' name and figure number. The preferred position of all illustrations should be indicated in pencil in the manuscript.

Photographs : Half-tone illustrations should be included only when essential. Good glossy prints with sharp contrasts between black and white areas should accompany the manuscripts; they should not be attached to manuscript pages. The size should be such that when the print is reduced to the normal size for reproduction (12×17 cm maximum), the detail is still clear. Magnification should be indicated with a scale line on the photograph. The authors' names and figure number should be given on the back of each photograph.

Tables should not repeat data which are available elsewhere in the paper. Each table should be typed on a separate sheet with due regard for the proportions of the printed page. They should be numbered consecutively with Arabic numerals. Tabulated matter should be clearly set out and the number of columns in each table should be kept as low as possible. Tables should have legends which make their general meaning clear without reference to the text and all table columns should have explanatory headings. Units of measure should be indicated in parentheses in the heading of each column. Vertical lines should not be used and horizontal rules used only in the heading and at the bottom. A one-column table may be up to 42 characters (letters and spaces) wide. A two-column table may be 90 characters wide. Footnotes to the tables are to be

placed directly below the table and should be indicated by superscript lower-case italic letters (*a*, *b*, *c*, etc.). Each table should carry on the back of the sheet the authors' names and figure number. The preferred position of tables should be indicated in pencil in the manuscript.

References to the literature must be indicated in the text by a small superior number referring to the list of references which must be inserted on a separate sheet at the end of the paper. The list should be arranged in alphabetical order by author and numbered in Arabic numerals. All authors' initials must be given after surnames. The year of publication should follow in parentheses. When journal articles are listed the journal name should be abbreviated in accordance with the *World List of Scientific Periodicals 1900—1960*, 1972, 4th edn, London : Butterworths Scientific Publications. If the journal is not in this list, the name should be given in full. The abbreviated journal title should be underlined to indicate italic type and followed by the volume number underlined with a wavy line to indicate bold type, the issue number in parentheses and then the inclusive pages. When books are listed, the order should be : author(s), year, book title, volume number, edition, pagination/inclusive pages, place of publication and publisher. When sections of a book are listed the order should be : author (s) of section, year, the word *In* followed by author of book, book title, volume number, edition, inclusive pages place of publication and publisher. The series title of a book should be given in parentheses after the publisher.

Examples :

Journal — ANGMOR, J.E., DICKS, D.M., EVANS, W. C. & SANTRA, D.K. (1972) *Planta Med.* **21**(4) : 416-420.

Book — SCHOKMAN, D. (1966) *Vegetable growing : local and exotic varieties*, 29p. Colombo : Agriculture Department.

Section of Book — ZITNAK, A. (1973) *In Chronic cassava toxicity : proceedings of an interdisciplinary workshop, London, England, 29-30 January 1973*, pp. 89-95. Ottawa : International Development Research Centre. (IDRC-010e).

Footnotes which are *indispensable* should be indicated in the text by small superior figures and listed on a separate page in the manuscript.

Abbreviations and Symbols recommended in the various parts of British Standard 1991 : *Letter symbols, signs and abbreviations* should be used. Authors are encouraged to use the S.I. System of units (see description in British Standard PD 5686 : *The use of S.I. Units*).

Authors whose papers contain mathematical expressions should submit a list of the symbols used carefully and clearly indicated for the guidance of the printer. This list will not appear in print.

Formulae and Equations : Equations should be typewritten and *quadruple* spaced. They should be started on the left margin and the number placed in parentheses to the right of the equation.

Nomenclature : Scientific names of plants and animals will be printed in italics, and should be underlined in the manuscript. In the first citation, genus, species and authority must be given. e.g. *Tylenchorhynchus claytoni* Steiner. In later citations, the generic name may be abbreviated to its initial letter. e.g. *T. claytoni*.

Special instructions in the fields of Physical, Chemical and Medical Sciences are available on application to the Secretary.

Short Communications : The Journal may include a limited number of short communications. Authors should submit short communications only when they believe that rapid publication of their results is of the utmost importance. A short communication must not exceed 1,200 words, i.e. 4 pages of copy inclusive of illustrations and tables. Short communications should be complete in their own right and suitable for citation. The title should indicate the content clearly as these papers do not carry abstracts.

Proofs : Corrected galley proofs must be returned to the Secretary without delay as directed. Failure to do so will result in delay in publication. Correction of proofs by authors must be restricted to printer's and similar errors. They should be marked in pencil. Any modification of the original text is to be avoided. Responsibility for correcting proofs rests entirely on the authors though editorial assistance will be provided.

Reprints : 50 reprints will be supplied free of charge for each article. Additional reprints can be ordered on the reprint order form which will accompany the proofs.

CONTENTS OF PREVIOUS ISSUES

Vol. 1 No. 1, August 1973

Vol. 1 No. 2. December 1973

Journal of the
National Science Council
of Sri Lanka

Vol. 2 No. 1 June 1974

Contents

Published by
The National Science Council of Sri Lanka
and Printed at Sri Lanka University Press, Katubedde.