



Title	Studies on the Extractives of Larch Report 11 : Determination of Flavonoids in Larix leptolepis
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Citation	北海道大學農學部 演習林研究報告, 27(2), 429-443
Issue Date	1970-11
Doc URL	http://hdl.handle.net/2115/20882
Type	bulletin (article)
File Information	27(2)_P429-443.pdf



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Studies on the Extractives of Larch
Report 11*: Determination of Flavonoids in
Larix leptolepis

By

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カラマツの抽出成分に関する研究

第11報 カラマツ (*Larix leptolepis*) のフラボノイドの定量

笹谷 宜志**・出町 秀也***・寺沢 実****

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Introduction

In the previous paper of this series¹⁾, the analysis of phenolic compounds from the heartwood was described. Two flavonols and two flavanols were isolated,

* Report 1 is "Analysis of Phenolic Compounds from the Heartwood of *Larix leptolepis*" in the series "Studies on the Extractives of Larch", Proc. Hokkaido Branch Japan Wood Res. Soc., No. 1, 57 (1968).

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and these were identified as taxifolin (dihydroquercetin : 3, 5, 7, 3', 4'-pentahydroxy flavanone), aromadendrin (dihydrokaempferol : 3, 5, 7, 4'-tetrahydroxy flavanone) quercetin (3, 5, 7, 3', 4'-pentahydroxy flavone) and kaempferol (3, 5, 7, 4'-tetrahydroxy flavone), respectively. Information that kaempferol can be isolated from heartwood of *Larix leptolepis* as a crystal is not yet available although kaempferol was found in extracts from heartwood of *Larix* sp. by means of paper partition chromatography²⁾.

It is well known that one of these flavonoids taxifolin is an anti-pulping agent for the calcium-base sulphite process^{3),4)}. The heartwood of *Larix* sp. is less susceptible to attack by wood-destroying organisms than the sapwood. The fungicidal properties of *Larix* sp. heartwood are similar to Hiba *Thujaopsis dolabrata* SIEB, et ZUCC., Hinoki *Chamaecyparis obtusa* SIEB. et. ZUCC. and Kuri *Castanea crenata* SIEB et ZUCC. These species are recognized as durable trees. The durability of a specific heartwood might be due to toxic material in the heartwood. Experimental research in this field has been done by a number of investigators. NISHIDA and co-workers^{5),6)} have demonstrated that wood phenolics distylin (taxifolin) is resistant to the attack of white rot *Polysticus sanguineus* (L) FRIES. and brown rot *Poria vaporaria* FERS. Also taxifolin is the dominant factor in Douglas-fir durability⁷⁾. Taxifolin is also readily converted to quercetin and possesses antioxidant activity preventing rancidity in fat oils and dairy products⁸⁾. The oxidation product of taxifolin, quercetin, also demonstrates effective antioxidant properties and, with some substrates, has greater antioxidant activity than taxifolin. The constituents of heartwood have several properties that effect utilization of the wood.

As a factor in the elucidation of the mechanism of heartwood formation, it is very important to determine the content of flavonoids in the wood of *Larix leptolepis* and also to understand the general pattern of variation in concentration within the stem.

It has been reported that the concentration of flavonoids in the wood of the western larch *Larix occidentalis* is greatest at the sapwood-heartwood boundary. Within the tree, a general pattern of decreasing concentration with increasing distance from this boundary to the pith and bark was evident in the cross-section of the western larch^{9),10)}.

The present paper reports the determination of the flavonoid content in the cross-section of the stem of *Larix leptolepis* using spectrophotometric methods in order to discover the pattern of flavonoid variation within the stem.

Experimental

1. Starting Materials and Sampling Procedures

In this investigation, the raw material used was the same sample used in Report 1 of the series. The tree was felled in Tomakomai College Experimental Forest, Hokkaido University, in October, 1967. A disk was collected from the tree trunk 1.3 meters (breast height) from the ground level. The tree had 38 annual rings at breast height and was about 30 centimeters in diameter. The sapwood

was wide, averaging about 2.7 centimeters, and the sapwood-heartwood boundary was well delineated. A strip 4 centimeters in width was taken from bark to pith along the radius of the disk. As shown in Fig. 1, a strip was divided into 8 sections, i.e. the bark was divided into 2 parts outer bark (B_0) and inner bark (B_1), sapwood into 2 parts (S_1 and S_2), heartwood into 3 parts (H_1 , H_2 , and H_3) and the pith area was not divided. Each section was allowed to air-dry and then shaved. The shavings of each section were reduced to dust in a Wiley mill until the meal of both bark and wood passed through a 40 mesh screen. The samples obtained were stored in polyethylene bags. The moisture contents of air-dried samples of wood and bark were 7.3% and 8.8%, respectively.

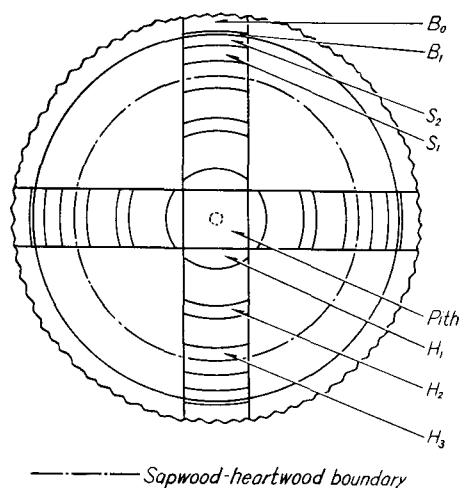


Fig. 1. Sampling mode.

2. Extraction Procedures and Stock Solutions

One gram sample of air-dried dust was placed in a 100 ml Erlenmeyer flask with 40 ml of methyl alcohol. The flask was fitted with a condenser and heated on a steam bath for 3 hours. Then the methyl alcohol was decanted.

It is well known that flavonoids are reduced to the corresponding cyanidin chloride by metal (magnesium or zinc)-hydrochloric acid reagents. In the Mg-HCl test, flavones, flavonols, flavanones and flavanonols are colored orange to purple red, but chalcones and isoflavones are negative. On the other hand, chalcones, flavones, flavonols and isoflavones are negative in Zn-HCl test, but flavanones and flavanonols are positive.

The decanted alcohol solution was treated with Mg-HCl and Zn-HCl. Methyl alcohol extraction was continued until the alcohol solution showed a negative reaction for flavanones. After the third extraction, extraction was done with 20 ml of methyl alcohol added to each sample. Finally, this procedure was repeated 4 times for pith, H_1 , H_2 and H_3 , 3 times for S_1 and S_2 , 10 times for B_1 and B_0 . Each residue was washed with a small amount of methyl alcohol and the washings were combined with the extracted alcohol solution. The total volume of these alcohol solutions, as stock solutions, was 150 ml for pith, H_1 , H_2 and H_3 ; 100 ml for S_1 and S_2 ; 200 ml for B_1 ; and 240 ml for B_0 , respectively. Each stock solutions for determination of the flavonoid content was kept at room temperature.

3. Ultra-violet Absorption Spectra of Flavonoids

Authentic specimens of taxifolin, aromadendrin, quercetin and kaempferol were dissolved in a 25 ml volumetric flask with methyl alcohol and 10^{-4} M solutions of each compound were prepared for scanning. Ultra-violet absorption spectra scanned

in neutral medium and alkaline medium using a 1N aqueous solution of sodium carbonate were obtained with a Hitachi EPS-3T Spectrophotometer. These results are shown in Figures 2, 3, 4, and 5.

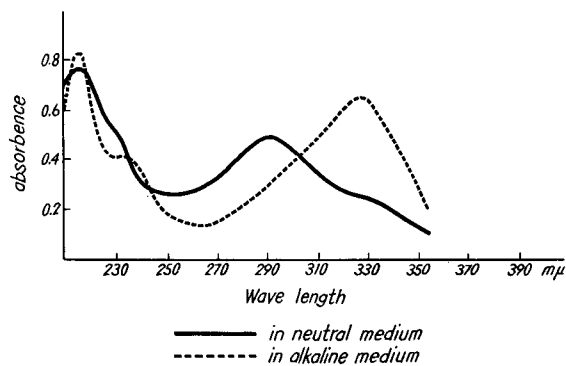


Fig. 2. Ultra-violet absorption spectra of taxifolin.

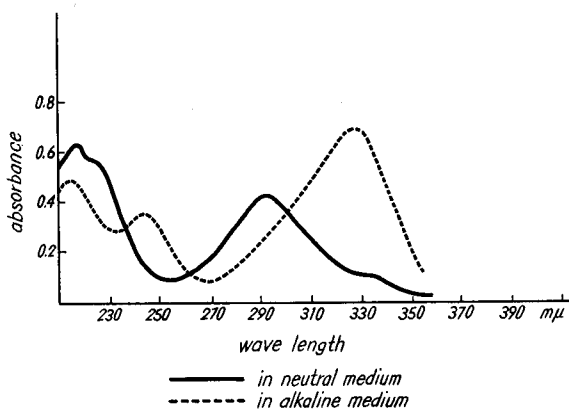


Fig. 3. Ultra-violet absorption spectra of aromadendrin.

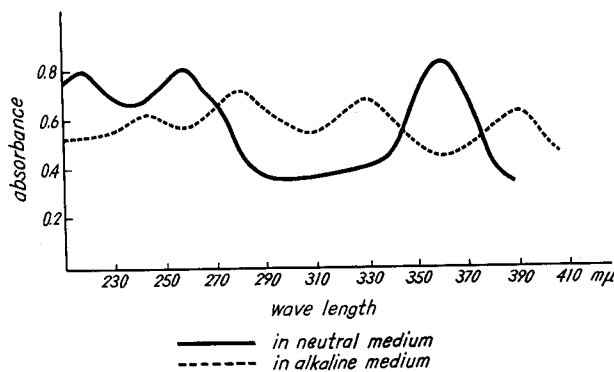


Fig. 4. Ultra-violet absorption spectra of quercetin.

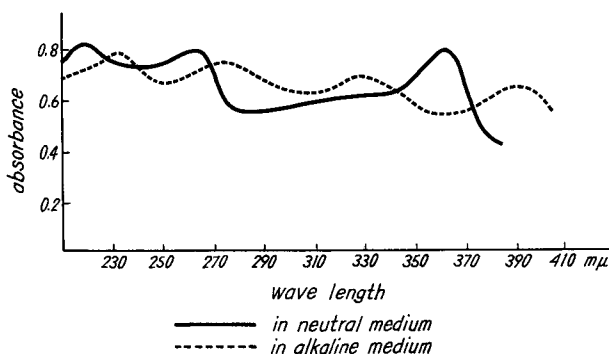


Fig. 5. Ultra-violet absorption spectra of kaempferol.

4. Calibration Curve for Determination of Flavonoids

It has already been reported that taxifolin in woody material is quantitatively determined with precision using the method of absorption photometry with visible^(9,10) and ultra-violet light^(11,12). In this work, flavonoids were determined by the method developed by KONDO and co-worker⁽¹¹⁾. From the results of the ultra-violet absorption spectra (experiment 3), it is difficult to determine the content of the four compounds by each calibration curve. Therefore, the content of taxifolin and aromadendrin was measured as flavanols and that of quercetin and kaempferol as flavonols. The content of flavanols and flavonols was calculated with the calibration curve of taxifolin and quercetin, respectively.

An authentic specimen of 0.695 mgm. of taxifolin was dissolved in a 25 ml volumetric flask with methyl alcohol and a 10^{-4} M stock solution of taxifolin was prepared for the determination of the calibration curve. This stock solution was diluted with methyl alcohol to produce solutions one-half, -third, -fourth, -sixth and -eighth the concentration of the stock solution. The absorbances of these six solutions at 294 $m\mu$ were plotted and the correlation between absorbance and concentration of the solution obtained. These results are shown in Table 1 and in Figure 6. After the measurement in neutral medium, a small amount of 1N sodium carbonate solution was added in a sample cell and the absorbance in alkaline medium at 326 $m\mu$ was measured. A few drops of alkali was sufficient for this purpose.

Table 1. Correlation between Absorbance and Concentration in diluted Solution of Taxifolin.

A multiple of dilution	Concentration (10^{-4} mol)	Absorbance	
		in neutral medium (294 $m\mu$)	in alkaline medium (326 $m\mu$)
1	0.9144	1.30	1.80
2	0.4572	0.595	0.940
3	0.3048	0.431	0.570
4	0.2286	0.305	0.445
6	0.1524	0.233	0.284
8	0.1143	0.156	0.220

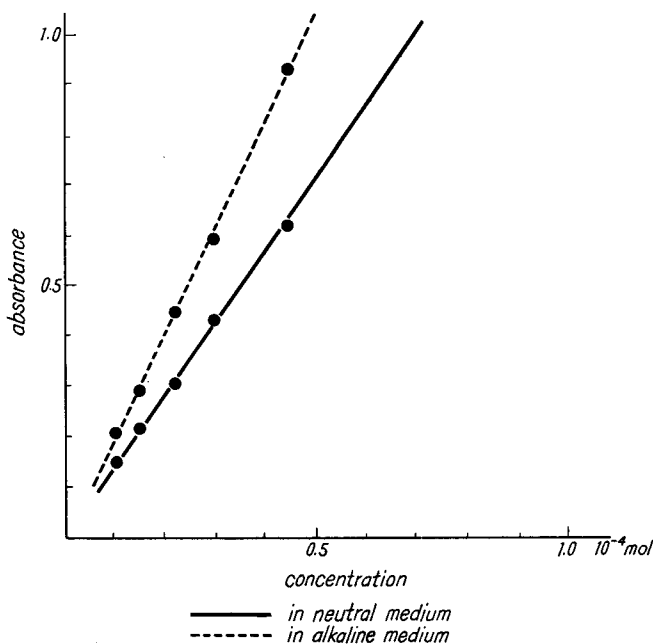


Fig. 6. Calibration curve of taxifolin.

The pH range was 8.4–8.6. A precipitate was not produced in the cell when an alkali solution was added. Similarly, the same portion of alkali solution was added to a reference cell and the absorbance was measured after 15 minutes.

For the measurement of quercetin, 1.114 mgm. of authentic specimen was dissolved in a 25 ml volumetric flask with methyl alcohol and this stock solution was diluted to one-third, -fourth, -fifth, -sixth, -eighth and -tenth. The absorbance of each quercetin solution was measured at 360 $m\mu$ for neutral solutions and at 392 $m\mu$ for alkaline solutions. These results are shown in Table 2 and Figure 7. A Hitachi EPU-2A Spectrophotometer was used.

Table 2. Correlation between Absorbance and concentration in diluted Solution of Quercetin.

A multiple of dilution	Concentration (10^{-4} mol)	Absorbance	
		in neutral medium (360 $m\mu$)	in alkaline medium (392 $m\mu$)
3	0.4918	1.06	0.541
4	0.3689	0.792	0.410
5	0.2951	0.638	0.328
6	0.2459	0.514	0.279
8	0.1844	0.389	0.199
10	0.1476	0.302	0.155

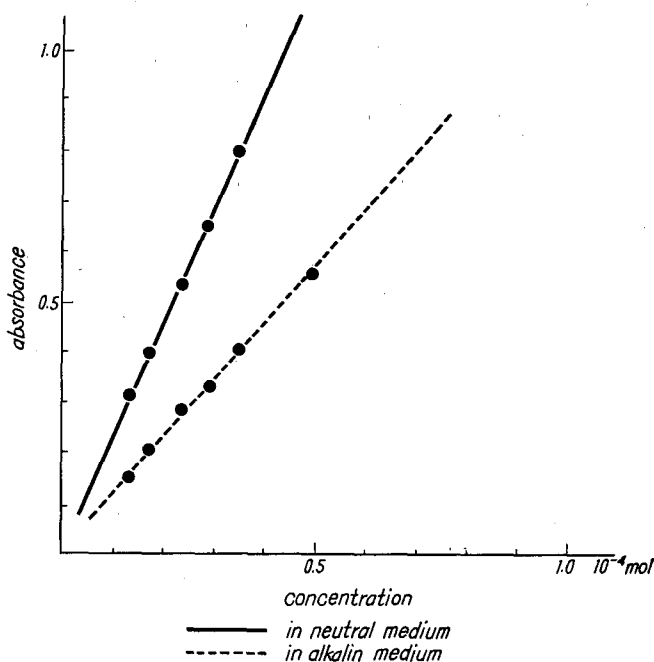


Fig. 7. Calibration curve of quercetin.

5. Determination of Flavonoids in the Extracts

To determine flavanone as taxifolin, the extracted stock solution was diluted suitably in order to produce an absorbance in a convenient range and was measured in neutral medium at $294\text{ m}\mu$. The concentration of flavanone was obtained from the curve correlating the measured absorbance and concentration. Then the flavanone content in raw material was calculated by substituting the flavanone concentration into the following equation (1).

$$X(\%) = \frac{n \cdot a \cdot M \cdot v}{W \cdot 1000} \times 100 \quad (1)$$

X : content to oven-dried raw material

n : a multiple of dilution

a : concentration of flavanone in the diluted solution

v : volume of extracted stock solution

M : molecular weight of authentic specimen

W : weight of oven-dried raw material

The flavonol content as quercetin was measured at $360\text{ m}\mu$ in the same way as flavanone. Also the determination of the content of flavanone and flavonol in alkaline medium at $326\text{ m}\mu$ and at $392\text{ m}\mu$ was carried out in the same way as the determination in neutral medium.

These results are shown in Table 3 and 4, and in Figures 8 and 9.

Table 3. The Content of Flavanonol as Taxifolin.

Each section	A multiple of dilution (ml)	Absorbance of diluted solution		Concentration of diluted solution (10 ⁻⁴ mol)		Content in raw material (%)	
		in neutral medium	in alkaline medium	in neutral	in alkaline	in neutral	in alkaline
Pith	150×24	0.476	0.547	0.34336	0.28034	3.92	3.20
H ₁	150×24	0.560	0.680	0.40266	0.34700	4.69	4.04
H ₂	150×24	0.700	0.930	0.50150	0.47227	5.86	5.52
H ₃	150×24	0.813	0.970	0.58127	0.49231	6.87	5.82
S ₁	100×24	0.205	0.170	0.15204	0.09147	1.68	0.71
S ₂	100×24	0.102	0.059	0.07933	0.03585	0.80	0.28
B ₁	200×24	0.622	0.367	0.44643	0.19017	7.06	3.01
B ₀	240×24	0.469	0.176	0.33842	0.09447	6.47	1.81

Table 4. The Content of Flavonol as Quercetin.

Each section	A multiple of dilution (ml)	Absorbance of diluted solution		Concentration of diluted solution (10 ⁻⁴ mol)		Content in raw material (%)	
		in neutral	in alkaline	in neutral	in alkaline	in neutral	in alkaline
Pith	150×1	0.800	0.478	0.37263	0.43128	0.176	0.204
H ₁	150×1	0.723	0.508	0.33765	0.45808	0.163	0.221
H ₂	150×1	0.900	0.565	0.41806	0.50900	0.202	0.246
H ₃	150×1	0.945	0.599	0.43851	0.53937	0.215	0.262
S ₁	100×1	0.302	0.258	0.14637	0.23476	0.047	0.076
S ₂	100×1	0.262	0.202	0.12820	0.18473	0.042	0.060
B ₁	200×4	0.462	0.686	0.21906	0.61709	0.574	1.616
B ₀	240×4	0.202	0.315	0.10094	0.28568	0.319	0.904

Results and Discussion

The ultra-violet absorption spectra of four flavonoids are shown in Figures 2, 3, 4 and 5. Taxifolin and aromadendrin in neutral medium have an absorption maximum at 294 m μ which is characteristic of flavanones. In alkaline medium, this absorption maximum is shifted to 326 m μ . On the other hand, quercetin and kaempferol show an absorption maximum at 360 m μ in neutral solution and an absorption maximum at 392 m μ in alkaline solution. As mentioned above, the taxifolin absorption curve is almost identical to the aromadendrin absorption curve and the quercetin absorption curve is almost identical to the kaempferol curve. The calibration curve of taxifolin is, therefore, employed for the measurement of flavanonol content and that of quercetin is employed for the measurement of flavonol content.

The stock solution (10⁻⁴ M) of taxifolin is diluted and six solutions of the dif-

ferent concentrations are prepared. The results of these measurements are shown in Table 1. The measurement of quercetin is done in a similar way and those results are tabulated in Table 2. The correlation between absorbance and concentration is shown in Figures 6 and 7. There is an obvious rectilinear relationship between absorbance and concentration in these figures. The results with these diluted solutions evidently satisfy Lambert-Beer's correlation. When the concentration of each solution is calculated from the graphs, there are unavailable errors introduced. In our measurement, the determination of the content of flavonoids in several solutions is computed by the equation which was derived from the methods of least squares.

The equations of each specimen in neutral and alkaline medium are as follows:

Taxifolin

$$\text{in neutral : } Y = 1.4165x - 0.01037 \quad (2)$$

$$\text{in alkaline : } Y = 1.9958x - 0.01255 \quad (3)$$

Quercetin

$$\text{in neutral : } Y = 2.2010x - 0.02016 \quad (4)$$

$$\text{in alkaline : } Y = 1.1195x - 0.0048 \quad (5)$$

Y : Absorbance ($-\log T$)

x : Concentration of dilute solution ($10^{-4} M$)

The diluted solution of the extracted stock solution from each section was analysed and the concentration was calculated by the above equation (2, 3, 4 and 5). Then, the content (%) of flavonoids in the raw material was calculated using equation 1. These results are shown in Table 3 and 4.

As mentioned before, the flavonoid content is considered to be the sum of taxifolin and aromadendrin even though other compounds may have contributed to the measured absorbance. However, from the results in the previous report (1), taxifolin and aromadendrin are the major flavanone components and taxifolin is the dominant constituent in methyl alcohol extracts. Likewise, the flavonol, quercetin, is the main compound in the flavonol group. Although the measured values do not indicate the exact content of taxifolin and quercetin, the measured values are satisfactory to study the variation of flavonoids within the stem.

As shown in Fig. 8 which shows the determinations in neutral medium, the content of flavanone within the disk gradually increases from pith to the sapwood-heartwood boundary. The values are pith = 3.92% → H_1 = 4.69% → H_2 = 5.86% → H_3 = 6.87%, respectively. On the other hand, the values decrease from the sapwood-heartwood boundary to the cambial zone. The flavanone content of S_1 and S_2 are 1.68% and 0.80%. Although bark is anatomically different from wood, the content of flavanone in bark is quite high, though it may be not related to their distribution directly. Flavonone contents are 7.06% in B_1 and 6.47% in B_0 .

In alkaline medium, the contents are pith = 3.20% → H_1 = 4.04% → H_2 = 5.52% → H_3 = 5.82% → S_1 = 0.71% → S_2 = 0.28% and B_1 = 3.01% and B_0 = 1.81%. These values

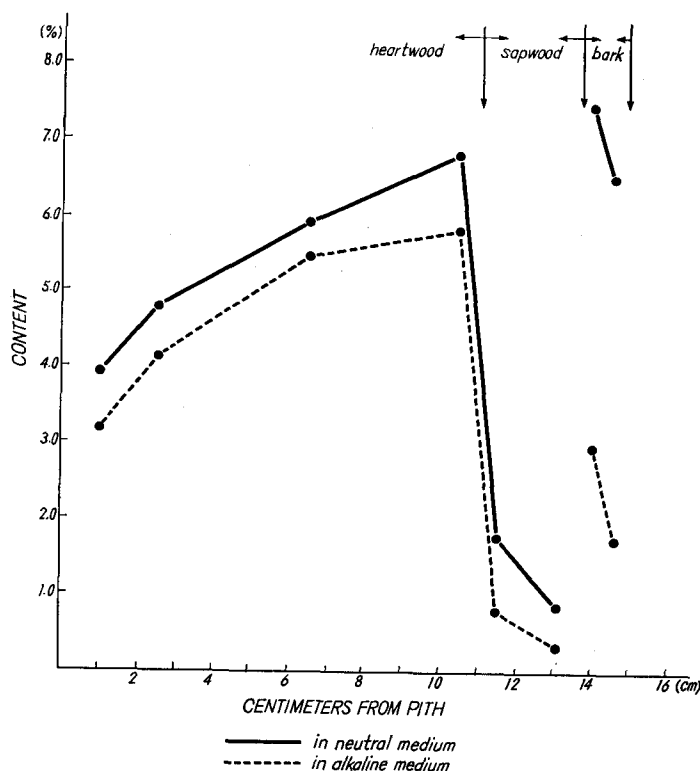


Fig. 8. Distribution of flavanone (as Taxifolin) of *Larix leptolepis*.

are lower than those of the neutral method. Flavanone contents in the bark are considerably reduced by alkali treatment.

It is interesting that the variation in flavanone content shows similar tendencies in both neutral and alkaline methods. The higher values in neutral medium seem to be due to co-existence of unidentified compounds other than taxifolin and aromadendrin, or alternatively, the values in neutral medium may affect the absorbance of flavone contained in the extracted stock solution at $294\text{ m}\mu$ in some way. As is generally known, the absorption maximum of many phenolic compounds is shifted to the visible region in alkaline solutions. The maximum of taxifolin is transferred to the longer wave length region with alkali and occurs at $326\text{ m}\mu$. This bathochromic behaviour of phenolics is a characteristic of each compound. When the stock solution is treated with alkali, the absorption maxima of some compounds are expected to be at wave lengths other than $326\text{ m}\mu$. As mentioned above, the flavanone contents of bark measured at $326\text{ m}\mu$ are remarkably decreased. Although it can not be definitely concluded, it is assumed that the bark extracts contain mainly substances other than flavanones, whose absorption maxima in alkaline medium are transferred to another wave length region outside $326\text{ m}\mu$.

Considering the accuracy of the measurements, it is more suitable for our purpose that the measurement in alkaline medium is practiced with more precision than that in neutral medium because the alkaline medium appears to remove the

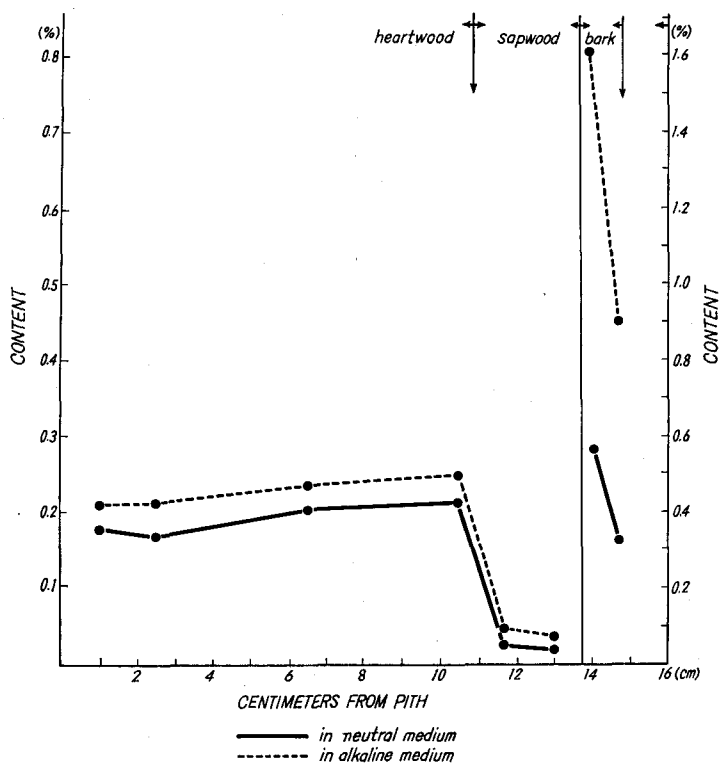


Fig. 9. Distribution of flavonol (as Quercetin) of *Larix leptolepis*.

interference to flavanone measurement.

The distribution pattern of flavonol as quercetin in the disk of larch is shown in Fig. 9. Using the neutral method, the contents are pith=0.176%→H₁=0.163%→H₂=0.202%→H₃=0.215% in the heartwood. The flavonol content increases slightly from pith to the sapwood-heartwood boundary, and decreases from this boundary to the cambial zone. The flavonol content decreases considerably like the variation of flavanone. The results are S₁=0.047% and S₂=0.042%. Within the bark, flavonol contents are B₁=0.574% and B₀=0.319%. When the contents are measured in alkaline medium, the contents of flavonol are as follows: pith=0.204%→H₁=0.221%→H₂=0.246%→H₃=0.262%→S₁=0.076%→S₂=0.060% and B₁=1.616% and B₀=0.904%. The content of flavonol in the disk is also increased at the sapwood-heartwood boundary and is reduced from this boundary to the pith and cambial zone. The content of flavonol, however, is only about 4% of the flavanone content. It is also remarkable that flavonol measured in alkali medium shows higher values compared to the content in neutral medium. This result is the converse of flavanone measured in the same media. It is well known that some phenolic compounds are changed to coloring matter in alkaline solution and light irradiated may be to absorbed at longer wave lengths region. Probably, the absorbance of the stock solution is strongly affected by compounds other than the known flavonols in alkaline medium and the measured absorbance gives a higher

value than that of neutral medium. In conclusion, the method in neutral medium is more advantageous to determination of flavonols compared with measurement in alkaline medium.

According to these experimental results, the pattern of flavonol distribution in the disk is very similar to the variation of flavanone but the flavanone content is considerably higher than the flavonol content. The flavanone content is calculated to be over twenty times higher than the flavonol content. The distribution pattern of phenolic compounds in wood is evidently in agreement with that in Douglas-fir, western larch and willow¹³⁾.

It has already been mentioned by KONDO¹¹⁾ that a rot of the heartwood of larch in the field has arisen in the ratio of twenty to one. This phenomenon also seems to be in agreement with the effect of higher flavonoid content in the heartwood.

Within the limits of this work, it cannot definitely be said why these flavonoids gradually increase from the cambial zone to the sapwood-heartwood boundary and then why these contents are at a maximum on the heartwood side of this boundary, and further, why these compounds slowly decrease toward the pith. A few aspects of the proliferation of the so-called heartwood constituents in heartwood have been reported^{14),15),16)} and such research has attracted the attention of many researchers.

If taxifolin and aromadendrin are the end products in the biosynthetic pathway, this does not easily explain why the content of flavanones is reduced toward the pith. In our first experiment of the series, we have observed that flavanones are converted to water insoluble red colored material when they were treated with an aqueous methyl alcohol which was used without purification. This substance was similar to the red colored material from inner bark. The formation of this compound seems to be effected by temperature, pH, and the presence of water but it is necessary to elucidate these relationships more carefully in a future study.

If the red colored compound, which may be related to the pigmentation of heartwood, is created in the heartwood and the content of flavonoids is decreased in the same situation, it is possible that some of these flavonols served in heartwood are converted into some other colored material, such as a catechin polymer or flavanone—other compound co-polymers in the vegetable tannins.

Conclusion

From the facts described above, the distribution pattern of the flavonoids in the larch disk gradually increases from S_2 to S_1 in the sapwood and increases considerably from S_1 to H_3 at the sapwood-heartwood boundary. The content of flavonoids is highest at this boundary and then slowly decreases from H_3 to pith in the heartwood. The flavanone content is about 1% in the sapwood and about 6% in the heartwood (H_3). This pattern of flavanone content agrees well with that of Douglas-fir and western larch, since the content of taxifolin in the heartwood was 1.6% in Douglas-fir and 1.8% in western larch.

When the content of flavanone in the bark was measured in neutral medium,

a large absorbance was measured because of absorbance by some compounds other than the known flavanones. Considering the fungicidal activity of larch heartwood and the inhibition of calcium-base sulphite pulping, the remarkable content of flavonoids in the heartwood should not be overlooked. Also, the relationship between the proliferation of heartwood constituents and the formation of heartwood may be a problem one should investigate. Since these constituents gradually decrease from the sapwood-heartwood boundary to pith in heartwood, as mentioned before, it is assumed that these compounds are converted to other substances in some way. Furthermore, the chemical studies of the heartwood constituents have important effects on the utilization of larch. It will be useful in solving the mechanism of heartwood formation to clarify the increase of these materials at the sapwood heartwood boundary.

In the future, more detailed experimental research is required.

Acknowledgement: The authors would like to acknowledge the continuing guidance and encouragement of Professor A. SAKAKIBARA and to thank Dr. Y. YASUE for sending the kaempferol. It is a pleasure to thank the members of the Institute of Wood Chemistry and the College Experimental Forests of Hokkaido University for their hospitality and encouragement.

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摘 要

前報に引続き、カラマツ *Larix leptolepis* のフラボノイドの含有量を吸光光度法を用いて定量した。さらに、樹幹内の半径方向に如何なる分布状態をもつかを、併せて検索した。

1. 既に同定された4種の化合物タキシホリン、アロマデンドリン、ケルセチンおよびケンフェロールの検量線の作成を試みたが、各化合物の紫外線吸収の極大値はタキシホリンおよびアロマデンドリン、ケルセチンおよびケンフェロール各々同じ波長領域に存在するため、4種の検量線を作成することは出来なかった。したがって、試料中のフラバノールの定量のためにタキシホリンの検量線を用い、一方、フラボノールの定量にはケルセチンの検量線を用いた。得られた検量線(第6図および第7図)から最小自乗法により回帰方程式を作成した。この方程式は次の通りである。

○タキシホリン

中 性 (294 m μ): $Y = 1.4165x - 0.01037$

アルカリ性 (326 m μ): $Y = 1.9958x - 0.01255$

○ケルセチン

中 性 (360 m μ): $Y = 2.201x - 0.02016$

アルカリ性 (392 m μ): $Y = 1.1196x - 0.0048$

Y : 吸光度 ($-\log T$)

x : 稀釈溶液中の濃度 (10^{-4} mol)

2. 胸高で採取した円板の各部位に含有されるフラボノイドは中性法、アルカリ法で各々測定された(第3表および第4表)。フラバノールについて、中性法での測定値はアルカリ法で測定した値より高い値を示した。とくに辺・心材境界の心材側(H₃)においては中性法、アルカリ法共に最高の値を示し、各々6.87%、5.82%であった。この値はタキシホリンとしてはかなりの量を示すが、抽出液中に存在する同じフラバノールのアロマデンドリン、フラボノール類又は他の少量の化合物の影響と思われる。しかし、アルカリ溶液中でのフェノール類の挙動から考えると326 m μ での測定においては、フラボノールや他の化合物の影響がより少なく、フラバノールの定量に際してはアルカリ法での測定が中性法における測定より優位と考えられる。一方、フラボノールの含有量はH₃において、中性法で0.215%、アルカリ法で0.260%の値を示した。フラバノールとは逆にアルカリ法での値が高くなっている。アルカリ中でのフェノール類は一般に可視部側で吸収するため、この作用の結果、アルカリ法の測定値が高い値を示したものと考えられる。したがって、フラボノールの定量には中性法の方がより適していると考えられる。フラボノールはフラバノールに比して僅かに4%であった。

3. フラボノイドの半径方向における分布は形成層付近より心材に向かって徐々にその含有

量が増加し、辺・心材境界で急激に増加し、その境界の心材側 (H₃) で最高に達し、それから以後髓に向って徐々に減少して行く型を示した (第8図および第9図)。この分布型はアメリカ西部カラマツやダグラスファーのタキシホリンの分布型とよく一致している。

4. 樹皮 (B₁) のフラバノールは中性法での測定により7.06%の値を示すが、アルカリ法で3.01%と極端に低い結果を示した。このことから内皮に含有される化合物はむしろフラバノール型の化合物が主成分でない事を示している。外皮についても同様の結果を得た。

以上の結果、心材成分といわれているこれらの化合物が辺・心材境界で急増する現象から考えて、心材形成に何らかの関係をもつと推察される。