

A Climatic Classification for Citrus Winter Survival in China

HUANG SHOU BO

Zhejiang Agricultural University, Hangzhou, Zhejiang, Peoples Republic of China

6 March 1990 and 29 June 1990

ABSTRACT

The citrus tree is susceptible to frost damage. Winter injury to citrus from freezing weather is the major meteorological problem in the northern part of citrus growing regions in China. Based on meteorological data collected at 120 stations in southern China and on the extent of citrus freezing injury, five climatic regions for citrus winter survival in China were developed. They were: 1) no citrus tree injury, 2) light injury to mandarins (*Citrus reticulata*) or moderate injury to oranges (*Citrus sinensis*), 3) moderate injury to mandarins or heavy injury to oranges, 4) heavy injury to mandarins, and 5) impossible citrus tree growth. This citrus climatic classification was an attempt to provide guidelines for regulation of citrus production, to effectively utilize land and climatic resources, to choose suitable citrus varieties, and to develop methods to prevent injury by freezing.

1. Introduction

China is one of the largest citrus producers in the world, and production is increasing (Pual 1988). Citrus trees grow well in warm and humid climates. Although the climate of China is generally favorable for citrus cultivation, citrus trees are often injured by severe winter cold. Freeze injury is the major limiting factor in citrus producing regions in the northern part of China.

According to the climatic conditions of the citrus winter survival that Matsumoto (1965) determined was the north boundary line for citrus cultivation in Japan. Tsertsbadze (1979) established the first regional climate division for citrus production in the Abkaz regions of the USSR. As an indication of the cold hardness of the satsuma orange (*Citrus unshiu*) using meteorological data, Huang et al. (1981) and Huang (1981) developed four and five climatic winter survival regions for the satsuma orange in the Zhejiang province of China. Research workers of The Chinese Academy of Agricultural Sciences (CASA) (1980) established four climatic zones for citrus trees in China. Yuan (1983) evaluated freeze injury to oranges in subtropical regions in China using cluster analysis. There is no report on the climatic classification for citrus winter survival in China. This paper discusses this question.

2. The geographic distribution of Chinese citrus

The main citrus types in China are mandarins (*C. reticulata* Blanco), sweet oranges (*C. sinensis* Osbeck), and pummels (*C. grandis* Osbeck). Examples of major citrus varieties are satsuma, Batangas mandarin (e.g.,

Ponkan), Tankan, Bendizao and Blood Red, Hamlin, Valencia, Washington navel, and Huangyan Bendizao. Citrus trees in China are distributed from 16° to 34°N and from 94° to 122°E. But the areas of economic cultivation are concentrated in the region from 30°N southwards and 102°E eastwards as shown in Fig. 1. Citrus grows from sea level to an altitude of 2600 m. According to 1987 statistics from the People's Republic of China, there are 716 thousand hectares of citrus plantations and 3.224 million tons of citrus produced per year. In 1986, Sichuan province produced the most, accounting for 24.8% of the total output. Guangdong province produced 21.2% of the total. Three other provinces Hunan, Zhejiang, and Guangxi made up 15.3%, 13.8%, and 9.6% of the total output, respectively. The total output of these provinces is about 84.5% of the whole (Fig. 1).

3. Survey of low temperatures and freeze injury to citrus

In the northern part of the citrus growing regions of China, there are no dry climates as in the subtropics, but there is ample moisture. Winter cold is the chief limiting factor of citrus tree distribution. The absolute minimum air temperature and annual average values and the probability that low temperatures would reach four values, e.g., -5°C, -7°C, -9°C and -11°C for 24 years of the representative stations in the northern part of the citrus growing regions in China are given in Table 1 and Fig. 2.

The meteorological data in Table 1 and Fig. 2 for the years 1957-1980 were obtained from the Meteorological Bureaus of China. Daily maximum and minimum temperatures, and wet- and dry-bulb temperatures were measured in a thermometer screen, sited on a large open plot of level ground at least 25 m in di-

Corresponding author address: Dr. Huang Shou Bo, Div. of Basic Courses, Zhejiang Agricultural University, Hangzhou, Zhejiang, 310029, Peoples Republic of China.

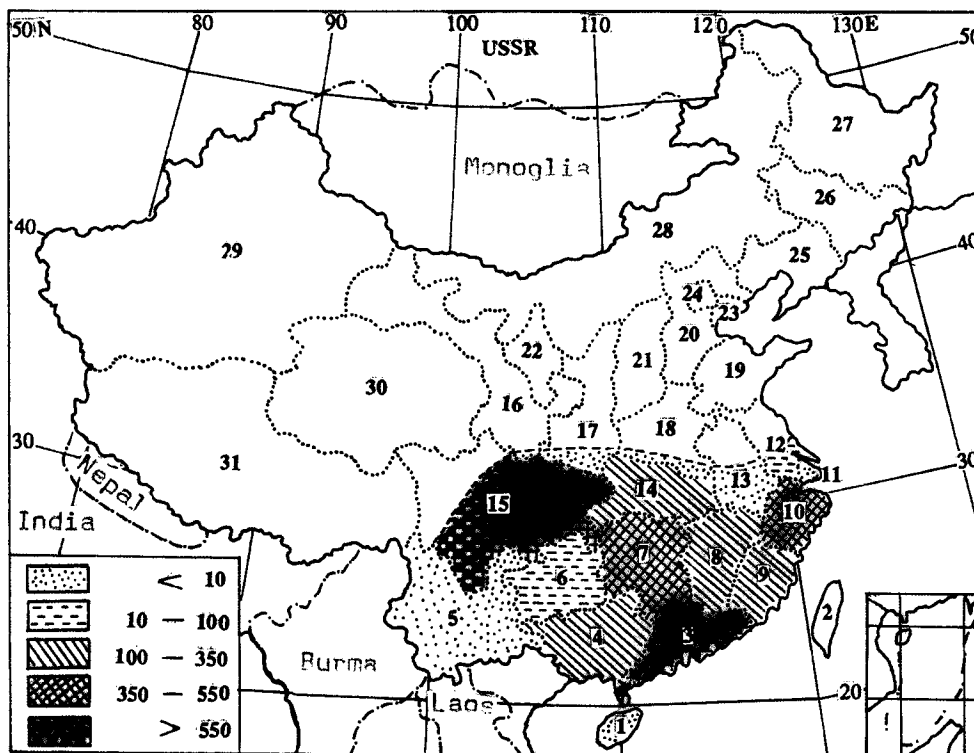


FIG. 1. Citrus fruit output (thousand tons) of each province in the People's Republic of China.

- | | | | | |
|--------------|-------------|--------------|--------------|--------------|
| 1. Hainan | 2. Taiwan | 3. Guangdong | 4. Guangxi | 5. Yunnan |
| 6. Guizhou | 7. Hunan | 8. Jiangxi | 9. Fujian | 10. Zhejiang |
| 11. Shanghai | 12. Jiangsu | 13. Anhui | 14. Hubei | 15. Sichuan |
| 16. Gansu | 17. Shanxi | 18. Henan | 19. Shandong | 20. Hebei |

ameter. The site was located away from large trees, buildings, and other obstructions. The reading of temperature had been taken at the standard clock times (e.g., Beijing time 0200, 0800, 1400, 2000) of the country, which the Beijing time is eight hours ahead of universal time coordinated (UTC). Thermometers were calibrated before being used.

Since 1949, citrus production in China has suffered from freeze injury three times, namely: 1954/1955, 1968/1969, and 1976/1977. The cold winter weather in 1954/1955 and 1976/1977 extended over a large area and caused particularly severe injury. In 1955, the yield of citrus fruit in Zhejiang province was only about half of that in 1954. During the winter of 1976/1977, 51% of the citrus trees in Zhejiang province suffered from freeze injury, with 3% of all trees dying. Since 1949, citrus production in Hunan province has been reduced three times due to freeze injury (Table 2).

4. Method and results of division

In order to understand the relationship between environmental factors and citrus freeze injury in China, an extensive investigation was undertaken in different citrus producing regions throughout the country. Injury to citrus from the freezing weather is caused by various factors, which can be divided into two aspects; botanical

and meteorological. The former aspect includes the citrus species, varieties, rootstock, plant age state of growth and maturity of branches, injuries by diseases and insects, the fruit yields in previous years, and picking time, which relates to the nutrition status in the plant. The meteorological aspect depends on the intensity of low air temperature and its duration, plus other meteorological factors during or after the freezing injury such as wind direction, wind speed, air humidity, and the meteorological conditions during thawing such as the temperature range between day and night. The minimum air temperature is most critical. Other factors, e.g., wind and moisture conditions, etc., are of secondary importance.

The meteorological indices of freeze injury to citrus have been reported by Praloran (1964). The part above the mandarin itself (*citrus reticulata*) showed frost damage when the low temperature is -11°C . Stems showed damage at -9°C and leaves at -7°C . Vassiliev (1955) confirmed that the part of the sweet orange above ground (*citrus sinensis* Osbeck) was damaged when the low temperature reached -9°C and the stems and leaves were damaged when the low temperature was -7°C . The author (1982) collected the freezing injury information on the satsuma orange (*citrus unshiu* Morc.) and sweet orange (*citrus sinensis* Osbeck)

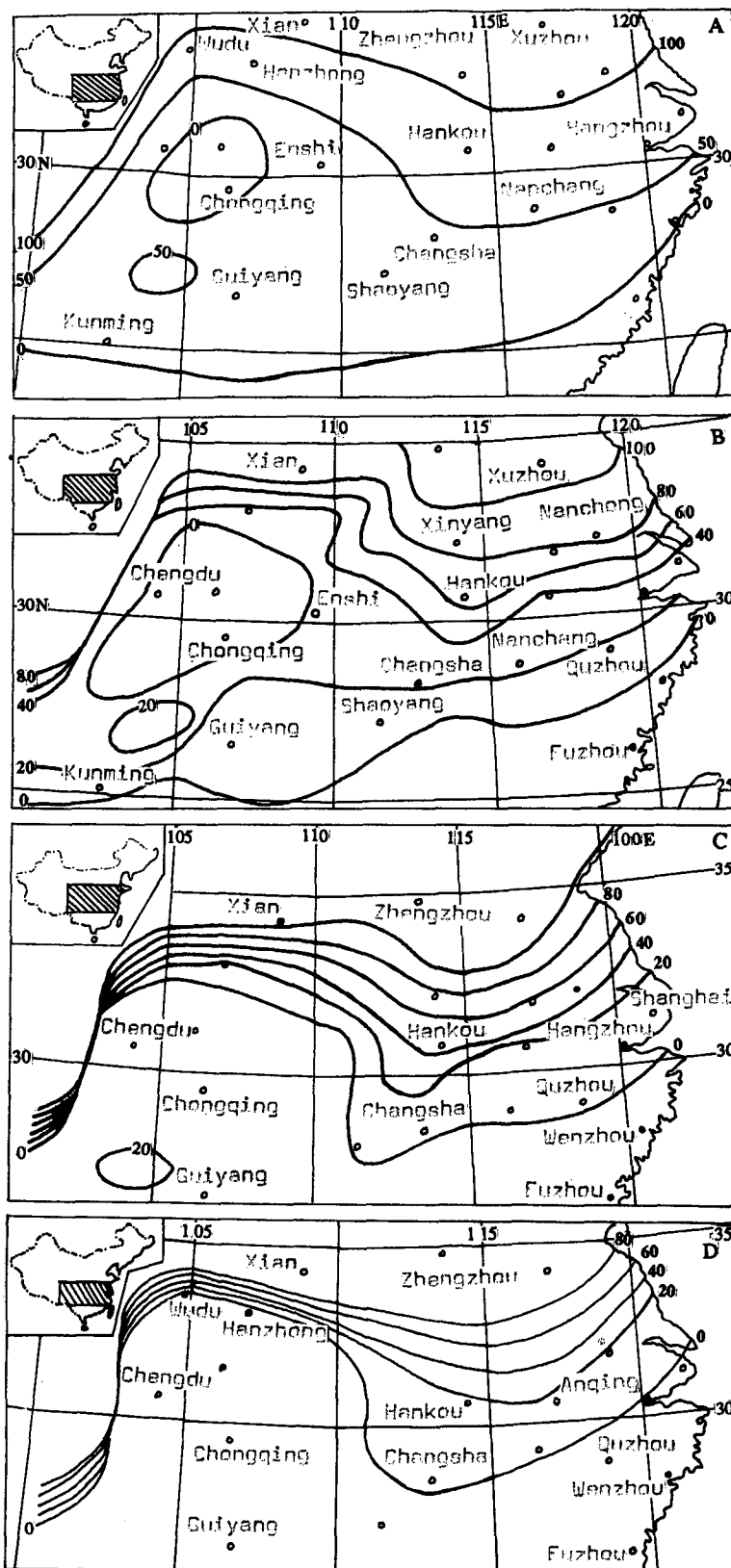


FIG. 2. The probability distribution of the absolute minimum air temperature less than -5°C (a), -7°C (b), -9°C (c), and -11°C (d) in the northern part of the citrus growing regions of China.

TABLE 1. Distribution of the average value of absolute minimum air temperature (\bar{T}_{\min}), absolute minimum air temperature (T_{\min}), and its probability (P) in the northern part of the citrus growing regions in China.

Names of stations	\bar{T}_{\min} (°C)	T_{\min} (°C)	P (percent)				Date of record
			< -5°C	< -7°C	< -9°C	< -11°C	
Xian	-11.2	-18.7	100	96	75	42	1957-1980
Zhennzhou	-12.4	-17.9	100	100	100	33	1957-1980
Xuzhou	-12.1	-22.6	100	100	83	63	1957-1980
Xinyang	-10.4	-16.9	100	92	54	25	1957-1980
Hefei	-9.1	-18.7	100	75	33	4	1957-1980
Nanjing	-9.6	-13.1	100	88	54	17	1957-1980
Wudu	-5.7	-8.1	75	17	0	0	1957-1980
Hanzhong	-6.7	-10.1	92	33	4	0	1957-1980
Hankou	-9.3	-18.1	92	75	38	13	1957-1980
Anqing	-7.2	-12.5	83	38	13	4	1957-1980
Shanghai	-7.0	-10.1	75	42	13	0	1957-1980
Hangzhou	-6.1	-9.6	58	25	4	0	1957-1980
Nanchang	-5.2	-9.3	54	29	8	8	1957-1980
Changsha	-5.2	-11.3	42	33	13	4	1957-1980
Changde	-5.4	-13.2	42	25	8	4	1957-1980
Enshi	-5.9	-12.3	13	8	4	4	1957-1980
Quzhou	-5.7	-10.7	46	21	8	0	1957-1980
Shaoyang	-4.6	-10.5	25	17	4	0	1957-1980
Guiyang	-4.9	-7.8	17	8	0	0	1957-1980
Huangyan	-4.6	-6.8	42	0	0	0	1957-1980
Nanchong	-0.8	-2.8	0	0	0	0	1957-1980
Chengdu	-3.4	-5.8	4	0	0	0	1957-1980
Chongqing	0.3	-1.8	0	0	0	0	1957-1980
Wenzhou	-2.6	-4.5	0	0	0	0	1957-1980
Fuzhou	0.8	-1.1	0	0	0	0	1957-1980

during the winter of 1954/1955 and 1976/1977 in Hunan, Hubei, Jiangsu, and Zhejiang provinces and Shanghai city in China. The freeze injuries index (FII) is given by the equation:

$$FII = \sum_{i=0}^5 ia_i / 6 \sum_{i=0}^5 a_i \cdot 100\% \quad (1)$$

here 0, 1, 2... are the freeze injury grade to citrus; grade zero is no freeze injury and grade five is citrus trees dying (Table 3). The terms $a_0, a_1, a_2 \dots$ are the number of plants with freeze injury for every freeze injury grade. The relationships between the absolute minimum temperature (AMT) and satsuma orange freeze injury (FII_{sa}), and sweet orange freeze injury (FII_{sw}) were calculated. The following regression equations and correlation coefficients were used:

$$FII_{sa} = -28.84 - 7.00AMT \quad (2)$$

$$R_{sa} = -0.8807^{**}$$

$$FII_{sw} = -31.56 - 9.42AMT \quad (3)$$

$$R_{sw} = -0.9451^{**}$$

According to the freeze injury index of the satsuma orange and sweet orange scatter diagram, three regions may be divided, namely light injury ($FII = 6\% - 30\%$), moderate injury ($FII = 31\% - 50\%$), and heavy injury ($FII > 50\%$). The characterizations of freeze injury of a citrus plantation are shown in Table 4. The temperature index of light injury, moderate injury, and heavy injury for satsuma oranges is more than -7°C , less than -9°C , and less than -11°C . The temperature

TABLE 2. Influence of three freezing years on citrus yield (thousand tons) in Hunan province since 1949.

Period of freezing injury	First time (1954/1955)		Second time (1968/1969)		Third time (1976/1977)	
	Yield	Percent	Yield	Percent	Yield	Percent
Before freeze injury	24.0	-100.0	39.3	100.0	42.3	100.0
After freeze injury	10.8	45.0	24.9	63.4	12.4	29.3
Reducing yield	-13.2	-55.0	-14.4	-36.7	-29.9	-70.3

TABLE 3. The characterization of freezing injury of every citrus tree (individual)*.

Grades	Rates of falling leaves (percent)	Conditions of freezing injury for stems and trunks
0	0	Normality growing
1	<25	Fall stems dying (FS)
2	25-75	FS and annual stems (AS) dying
3	>75	FS, AS, and perennial stems (PS) dying
4	100	FS, AS, PS, and big stems (BS) dying
5	100	FS, AS, PS, BS, and the trunk dying

* There are no flowers and fruits on the citrus tree during the China winter due to freezing weather.

index for sweet oranges is more than -5°C , less than -7°C , and less than -9°C .

Citrus is a perennial plant. All citrus trees in the citrus orchard died in freeze injury. Therefore, for the sake of guarantee, we have fixed the economic benefit of citrus production; the probability of low temperature should be less than 20%.

Agroclimatic indices such as mean air temperature and mean minimum air temperature of the coldest month, the average absolute minimum air temperature, absolute minimum air temperature, and probability have been carefully compared. At last we decided to

TABLE 4. The characterization of freezing injury from a citrus plantation (colony).

Names of freezing injury to citrus	FII (percent)	Rate of reducing yields (percent)
No injury	<5	0
Light injury	5-30	<25
Moderate injury	31-50	25-55
Heavy injury	51-75	56-80
Very heavy injury	>75	>80

use the absolute minimum air temperature of -5°C , -7°C , -9°C , -11°C and the probability of dividing climatic indices for citrus winter survival in China (Table 5).

According to the cold hardiness of citrus trees, the absolute minimum air temperature collected at 120 meteorological stations in southern China and the conditions of citrus freeze injury were divided into five climatic regions for citrus winter survival in China, listed in Table 5. These are 1) no citrus tree injury, 2) light injury to mandarins or moderate injury to oranges, 3) moderate injury to mandarins or heavy injury to oranges, 4) heavy injury to mandarins, and 5) impossible citrus tree growth (Fig. 3). Region I includes south China (I_a) and Sichuan Basin (I_b). Region II includes hill regions south of the Yangtze River (II_a) and around

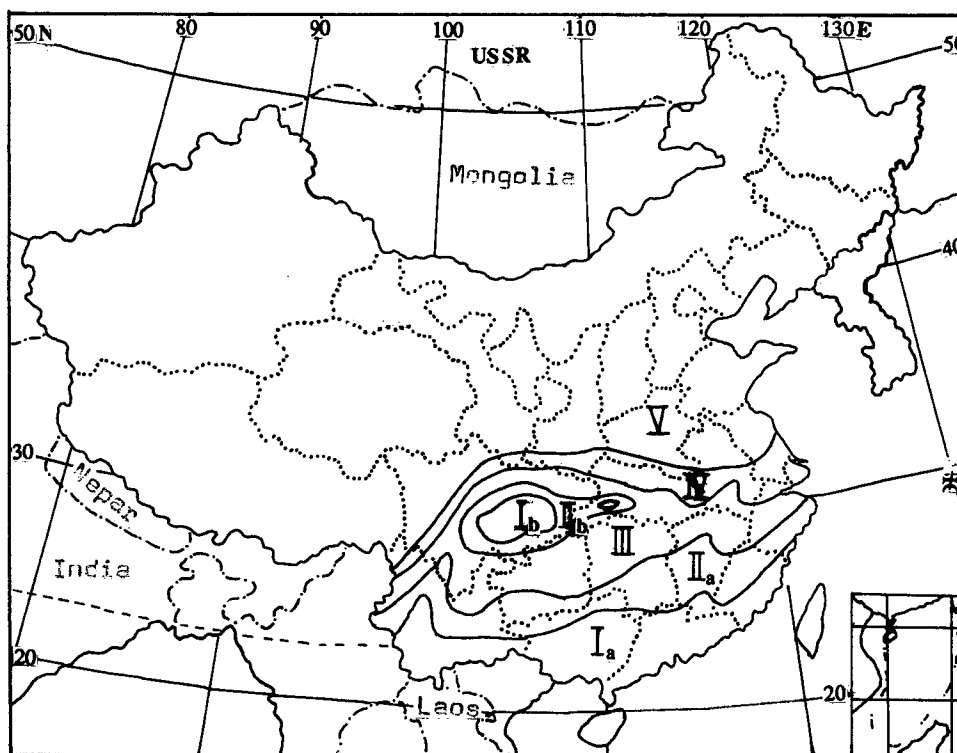


FIG. 3. A climatic classification for citrus winter survival in China.

TABLE 5. The climatic index for citrus winter survival in China.

Codes	Name of winter survival citrus regions	T_{\min} (°C)	The probability of low temperature (percent)			
			< -3°C	< -5°C	< -7°C	< -9°C
I	No citrus tree injury	> -5	<20			
II	Light injury to mandarins or moderate injury to oranges	> -7		<20		
III	Moderate injury to mandarins or heavy injury to oranges	> -9			<20	
IV	Heavy injury to mandarins	> -11				<20
V	Impossible citrus tree growth	≤ -11				≥20

the region of Sichuan Basin (II_b). Region III is the plain region south of the Yangtze River. Region IV is the plain region north of the Yangtze River. Region V is north and west of China.

In order to avoid or reduce the loss of freezing injury to citrus, according to the cold resistance of citrus species, regions without freezing temperatures or light freezing injury should be chosen to grow citrus. Regions I and II, situated in the southern most part of China, are suitable districts for both mandarin and orange growing. In region III, local microclimates should be carefully selected for citrus growing to avoid winter freeze injury. In general, it is not recommended to grow citrus trees in region IV. Citrus growth is impossible in region V.

5. Conclusions

China is one of the largest citrus producers in the world, with a growing area of over 700 thousand hectares, and in recent years an annual production of more than 3.224 million tons. Main citrus types in China are mandarin and sweet orange. Since 1949, citrus trees have been severely injured three times from freezing weather. This became the limiting factor to citrus growth in the northern part of citrus growing regions of China. Winter freeze damage is the main calamity in citrus growing regions of China.

According to the freeze injury temperature index for different citrus types the absolute minimum air temperatures in citrus growing regions of China, the conditions of citrus freeze injury permitted the division of China into five climatic regions for citrus winter survival. In order to avoid or reduce the loss of freezing injury to citrus, regions without freeze injury should be chosen to grow citrus.

Acknowledgments. The author acknowledges the help of Dr. H. A. Bridgman and Dr. G. N. McIntyre, Department of Geography, The University of Newcastle, New South Wales, Australia.

REFERENCES

- Huang, S. B., 1981: An investigation of freezing injury regionalization of citrus in Zhejiang province. *Meteorol. Mon.*, **3**, 24–25. (in Chinese)
- , 1982: An investigation in relation to satsuma orange freeze injuries temperature index. *Acta Horti. Sin.*, **9**(4), 21–25. (in Chinese, with English abstract)
- , 1983: Injury to citrus from freezing weather and its geographical distribution in the northern part of citrus-growing regions of China. *Acta Agri. Univ. Zhejiangensis*, **9**(4), 373–384. (in Chinese, with English abstract)
- , 1986: Geographical distribution of injury to citrus from freezing weather in the northern part of citrus-growing regions of China and its defending technology. *Proc. of China-United States of America Citrus Symposium, Chongqing CAAS*, 101–120.
- , and Hu, G. L., 1981: An investigation on the climate zones in relation to winter-hardiness of citrus in Zhejiang province. *J. Zhejiang Agri. Univ.*, **7**(1), 11–25. (in Chinese with English sum)
- Matsumoto, Z. U., 1965: Culturics and physiology of citrus. *Asakura Honye*, 35–36. (in Japanese)
- Praloran, J. C., 1964: The low temperature problem of citrus cultivation: the critical temperature of cold-resistant. *Fruits*, **9**(2), 61–92.
- Pual, B., 1988: China: rising star in the citrus world. *Citrograph*, **73**(3), 43–47.
- Research workers of the Laboratory of Agricultural Meteorology in the Chinese Academy of Agricultural Sciences, 1980: A study of climatic regionalization of citrus in China. *Agri. Meteorol.*, **3**, 13–18. (in Chinese)
- Tsertsbadze, S. I., and G. G. Meladze, 1979: A climatic regionalization for winter survival citrus trees in Abkaz regions in UUUR. *Proc. of the HIGMM*, **69**, 82–89. (in Russian)
- Vassiliew, A. V., 1955: *Agrometeorology*. Hydrology and Meteorology Press, 147–149. (in Russian)
- Yuan, J. Z., 1983: Cluster analysis for freeze injury to orange of subtropics district in China. *Indistinct Mathematics*, **1**, 87–92. (in Chinese, with English abstract)