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A possibility of influence factors on winter physical damage of grapevines in a snowy vineyard

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Summary

Hokkaido in northern Japan is a typical subpolar region and wine production using traditional cultivars can be done recently. However, there is an issue that the grapevines have short life spans in snowy central Hokkaido. This study investigates the effect of snow itself and its interaction with vineyard slope and grapevine stiffness on physical stress. In comparison of the flatness of the vineyard, the distortion of the basal trunk in the slope zone was greater than in the flat zones in the snowy mid-season. In comparison between cultivars, the distortion of the basal trunk in the *flexible* 'Kerner' was greater than in *rigid* 'Gewürztraminer', even in the flat zones. The magnitude of the distortion coincides with the mortality of grapevines. Although the changes in distortion showed a transition in just two winter durations, these results suggested a possibility that the snow cover might be linked to one of the physical damages of grapevines in vineyards in heavy snowy regions.

Key words: distortion; slope; snow cover; stiffness; trunk.

Introduction

Hokkaido is the northernmost island in Japan and is a typical subpolar region where the minimum air temperature reaches minus 40 degrees in inland areas in winter (JMA 2022). Nowadays, however, Hokkaido plays an important role in Japanese wine production, having the most acreage of vineyards and the highest class of production quantity of wine grapes in Japan (MAFF 2019).

Wine cultivation in Hokkaido was first tried in the eastern regions where there is less snowfall in the 1960's. However, without snow cover, the grapevines were susceptible to frost injury and burying grapevines in the soil every year was necessary for successful wintering. Winters with little to no snow cover and subzero temperatures can cause vine dieback and death (Davenport *et al.* 2008). Thereafter the breeders made efforts to develop some superior cold tolerant *Vitis vinifera* varieties, which were selected from bud mutations, and which were crossbred with *V. amurensis,* a native Hokkaido variety, which led to stable wine production (Hirota *et al.* 2006, Tsumura *et al.* 2019).

In the central region of Hokkaido where there is more snowfall compared to the eastern area, the grapes can survive in snow cover in winter, however the traditional *V. vinifera* grapes which belong to Region I, were also unsuccessfully cultivated. However, the possibility of stable wine production has increased due to recent climatic changes (Hirota *et al.* 2017). Even so, a new issue that vineyards in this region face is having to frequently renew vines because of their short life span (Nagata *et al.* 2014).

In eighty percent of countries in the EU, the majority of grapevines in vineyards are over 30 years old (Carbone *et al.* 2019), and at vineyards in California USA, the productivity of grapevines does not decline for over 20 years if they do not contract any diseases (Munkvold *et al.* 1994). However, the wine producers in the Sorachi district in central Hokkaido, which has thirty percent of the vineyard acreage in Hokkaido, complain about wine grapevines having a shorter life span (Hirakawa *et al.* 2014).

Under natural conditions, the life spans of grapevines is reduced by approximately 10 years, though the trend is remarkable in snowy regions with snow piles up to 2 meters (Saltanat 2020). Described above, the advantages of snowfall outweigh the disadvantages for viticulture in Hokkaido and the best way is to let the vines be covered naturally with snow, however, the wine producers in Hokkaido noticed the weakened grapevines after snow melting every spring.

Many researchers indicated frost damage as a factor emaciating wine grapevines in winter (Trought *et al.* 1999, Dami *et al*. 2016, Horiuchi *et al.* 2021). Other factors such as herbicides (Ball *et al.* 2014), vine nutrition (Chozinski *et al.* 2013), insect and mite damage (Duso *et al.* 2012), and vine diseases (Munkvold *et al.* 1994, Mondello *et al.* 2018) have also been claimed in previous studies to weaken grapevines. In a questionnaire to Hokkaido grape farmers, when asked what 'the specific cultivar that farmers abandoned and the reasons?', they stated the diseases in white grapes and the coloring disorder in black grapes (JVA 2020). However, the articles or reports which referred to the effect of snowfall or snow cover itself on grape's life span are quite limited (Tenuta 2019). Vineyard farmers in Hokkaido actually lower grapevines during the winter season so that they will be covered with snow in order to protect them from severe cold temperatures; therefore, it is possible that snow cover itself could affect growing conditions (Nemoto *et al.* 2016).

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In this study, the factors influencing wine grape life span at a vineyard in the Sorachi district, a snowy region in Hokkaido, were investigated setting up the hypothesis that physical damage from snow cover is a direct factor in the short life span with location (flat or slope) and the hardiness of the grapevine (two cultivars) being related factors.

Material and Methods

Vineyard and grapevine in Experiment 1: The first experiment was conducted in winter from autumn 2019 to winter 2020 at Tsurunuma winery (lat.43°27′43″N, long.141°48′11″E, altitude: 110 m above sea level), in Urausu town, Sorachi district, Hokkaido (Fig. 1A). The experimental area is located approximately 100 km from Sapporo, a snowy region where the snowfall depth is frequently more than 1 m in winter. However, the experimental year from 2019 to 2020 was a record year for low snowfall (Tab. S2, measured at Bibai 15 km from Urausu). The cordon can be seen on the snow surface in December, 2019 (Fig. 1B), and cannot be seen in February when the snow depth should have been deepest in 2020 (Fig. 1C). All grapevines are planted 150 cm apart, and are trained with a 'single cordon style' as is a typical vine training method in Hokkaido vineyards (Fig. 1D). The cordons expand horizontally at a height of 75 cm from the ground surface, the angle between the basal trunk and ground surface is kept at approximately 45°. This training method is suitable for regions with heavy snowfall where plants can overwinter under the snow. That means it is not necessary for the grape cultivars to have strong cold resistance. Every year the cordon is detached from the training wire before it snows to avoid having the wires broken by snow weight (Fig. 1B), and raised up and bound to the wire in early spring after the snow melts (Fig. 1D).

The experiment consists of two different experiments. In Experiment 1, the effect of slope on the physical stress of grapevines caused by snow cover and the injury suffered were focused on. Eleven or twelve-year-old 'Gewürztraminer' grape cultivars were used, and grapevines with similar morphological traits were selected for the comparison (Tab. 1). The flat and slope zones had an average obliquity of 1.0° and 9.2°, respectively.

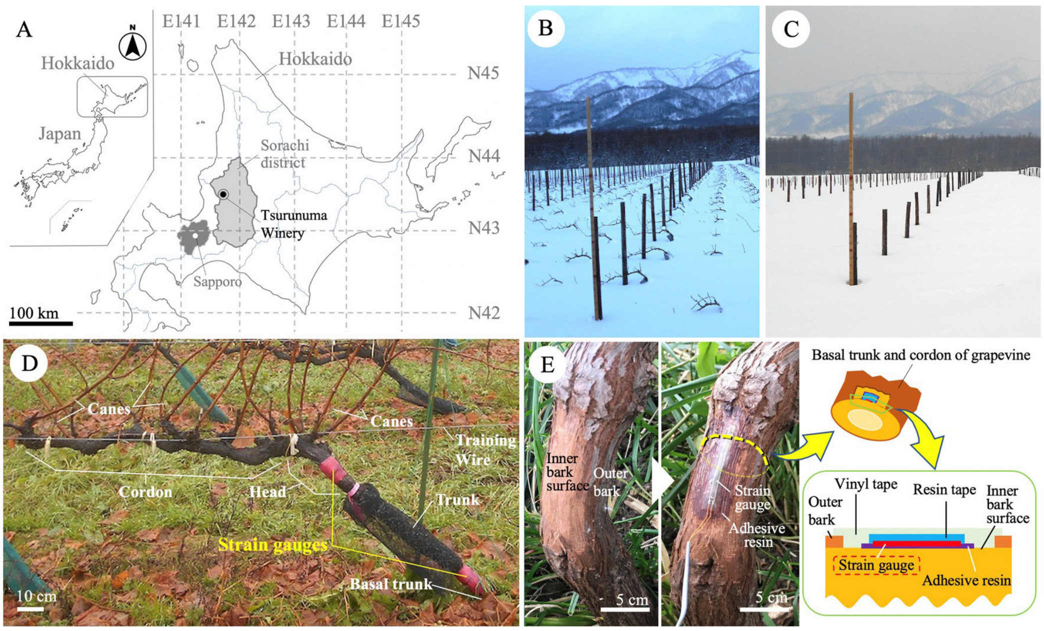

Fig.1 **A**: The location of experimental site, Tsurunuma Winery in Hokkaido. **B-D**: Seven-year-old vine of 'Gewürztraminer,' on December 20 in 2019 (**B**), February 28 in 2020 (**C**), November 27 in 2019 (**D**). **D**: The typical vine trained in 'single cordon' with the parts of the plant named and the positions of strain gauges shown. **E**: The anatomical scheme of the attachment of a strain gauge on grapevine.

Table 1

Geographical traits of each zone (flat and slope) and Morphological traits of 'Gewürztraminer' grapevine in the winery in 2019-2020

Geographical traits				Morphological traits									
Zone	Averaged incline (°)			Age (year)	Circumference (mm)						Length of Cordon (mm)		
					Basal trunk			Cordon					
Flat	1.0	(0.4)	***	12	722	(28)	ns	158	(2)	ns	1274	(137)	ns
Slope	9.2	(0.2)		11	688	(25)		161	(8)		1180	(93)	
P value			*0.0000128*	-			*0.398*			*0.738*			*0.586*

Numbers in parenthesis means S.E.

*** represents significance at 0.1% of student's *t*-test (one-side test, n = 5), ns means not significant.

Table 2

Geographical traits of experimental flat zones and morphological traits of two grapevine cultivars in the winery in 2019-2020

Cultivar	Geographical traits: Averaged incline (°)			Morphological traits: Age (year)	Circumference (mm): Basal trunk			Circumference (mm): Cordon			Length of Cordon (mm)		
'Gewürztraminer'	1.4	(0.4)	ns	7	650	(36)	ns	131	(6)	†	1334	(137)	ns
'Kerner'	1.0	(0.2)		7	712	(35)		117	(4)		1142	(123)	
P value			*0.187*	-			*0.252*			*0.083*			*0.328*

Numbers in parenthesis means S.E.
† represents significance at 10 % of student's *t*-test (one-side test, n = 5), ns means not significant.

Vineyard and grapevine in Experiment 2: In Experiment 2, the varietal differences in the physical stress and injury between two cultivars in the flat zones of the vineyard were focused on. The cultivars 'Gewürztraminer' and 'Kerner', each having a different rigidity as reported by farm managers, were used. Seven-year-old cultivars of each were used, and grapevines with similar morphological traits were selected as much as was possible (Tab. 2). The zones where the grapes are cultivated are the same as the flat zones.

As it is explained later, the distortion of grapevines in Experiments 1 and 2 were measured in winter 2019-2020. The distortion in 2021-2022 was also measured to confirm the phenomenon in the first winter from 2019-2020. At the second distortion measurement, 9-year-old grapevines with similar morphological traits were used (Tab. S1). Before the second winter's experiment, the soil water content in the soil surface and at a depth of 20 cm were measured separately at the flat and slope zones using a soil moisture sensor (SM150 Soil Moisture Kit, Delta-T Devices, London, UK).

Strain gauge for distortion: As described above, the grapevine's distortion in two winters (from autumn 2019 to winter 2020, and from autumn 2021 to winter 2022) were measured. The measurement of the distortion of the grapevine's surface was conducted using a strain gauge with a length of 30 mm designed for woody samples (single element, PFLW-30-11, Tokyo Measuring Instruments Lab, TML, Tokyo, Japan). A strain gauge converts the mechanical material strain due to changing hygrothermal conditions into a change in electrical resistance. To average out the strain distribution in heterogeneous materials such as wood, a gauge length of 4 to 5 times the heterogeneities is required. The strain gauges have a nominal resistance R_0 of 120 ± 0.5 Ohm, a gauge factor K of 2.13, and pre-attached extension lead wires of 1 m. The gauges were attached to the head and rootstock on the trunk (Fig. 1D), then the change in resistance ΔR (με) was monitored monthly with a handheld data logger (TC-32K, type S-2770, Tokyo Measuring Instruments Lab, TML, Tokyo, Japan). A ΔR was calculated by subtraction of initial value and measured value. The gauges were set up on the trunk surface with an adhesive resin (PS EF05F, Tokyo Measuring Instruments Lab, TML, Tokyo, Japan) that bonded to the grapevine surface with two-component room-temperature-curing polyester adhesive, resin tape (SB tape, Tokyo Measuring Instruments Lab, TML, Tokyo, Japan) and vinyl tape (VM tape, 3M Scotch, MN, USA). After a thorough surface cleaning removing the outer bark, the typical procedure for strain gauge adherence was followed as shown in Fig. 1E. The monitoring started on December 26, 2019 (or December 20, 2021) and continued until April 23, 2020 (or April 26, 2022).

In this study, it could not be distinguished the distortion caused by the operation for the maintenance which the vine was moved up and down to the training wire every spring and autumn from the distortion caused by snow cover itself. Therefore, the snow covering stress was defined including the damage caused by the operation such as the training work.

Mortality of grapevine: The mortality of grapevines was checked every spring for 5 years from 2016 to 2020. When the cordon was lifted up to the wires, the withered grapevines were checked, and the mortality was calculated by dividing the surviving grapevines of the cultivars by the withered grapevines after the winter.

The stress-wave velocity: The stress-wave velocity of living grapevines was determined using the method described in the previous report (Ishiguri *et al.* 2011). Stress-wave propagation time was measured from 0 to 50 cm above ground level using a commercial handheld stress-wave timer (Microsecond timer, FAKOPP Enterprise Bt., Fenyo, Hungary) at three positions of the grapevine; the rootstock, head and cordon. The stress-wave velocity ($mm \cdot s^{-1}$) was calculated by dividing the distance between sensors (a few decimeters) by the stress-wave propagation time. Young's modulus of wood can be evaluated nondestructively using the stress-wave velocity (Ishiguri *et al.* 2013).

Statistics: Each experiment described above had 5 replications and the statistical test for differences among cultivars was done in accordance to the analysis of variance (ANOVA), a Student's *t*-test and Tukey-Kramer's multiple comparative tests. The significance in the analysis of variance (ANOVA) was calculated for the split-split plot design (Little and Hills 1978). Other statistical analyses were done using Statcel4 (developed by Yanai, OMS, Japan), which is an add-in form in Microsoft Excel 2019 for Windows.

Results

Comparison between grapes cultivated in flat and slope zones (Experiment 1): At first, the distortion in basal trunk and head of 'Gewürztraminer' grapevines in flat and slope zones was measured using the strain gauge's value, ΔR (Tab. 3). The effect of zone was significant in December, and the effect of position was significant in January and February. The ΔR values from slope zones were larger than those from flat zones, and the ΔR values of the basal trunk was larger than that of the head. Additionally, the interaction between zone (flat or slope) and position (basal trunk or head) was also significant in January and February. All significant changes were not detected in March and April.

Next, the transition of ΔR values, that is distortion, in basal trunk and head of 'Gewürztraminer' grapevine in flat and slope zones are shown in Fig. 2. The distortions in the head in December and in the basal trunk in January and February of grapevines in the slope zones was significantly more than in the flat zones.

The mortality of 'Gewürztraminer' grapevine from 2016 to 2020 were 15.2 (± 0.9) % in flat zones and 20.9 (± 1.2) % in slope zones, respectively. The averaged mortality of grapevines over 5 years in the flat zones was less than that in the slope zones significantly (p = 0.0001, student's t-test (n = 5)).

The soil moisture at soil surface were 21.9 (± 1.6) % in flat zones and 16.9 (± 1.4) % in slope zones, respectively. At 20 cm depth of soil, the soil moisture was 16.5 (0.9) % in flat zones and 17.1 (± 1.7) % in slope zones, respectively. The soil surface moisture in the flat zones was slightly higher than that in the slope zones (p = 0.085, student's t-test (n = 6)), however that at 20 cm depth showed no difference of soil moisture between flat and slope zones (p = 0.793, student's t-test (n = 6)).

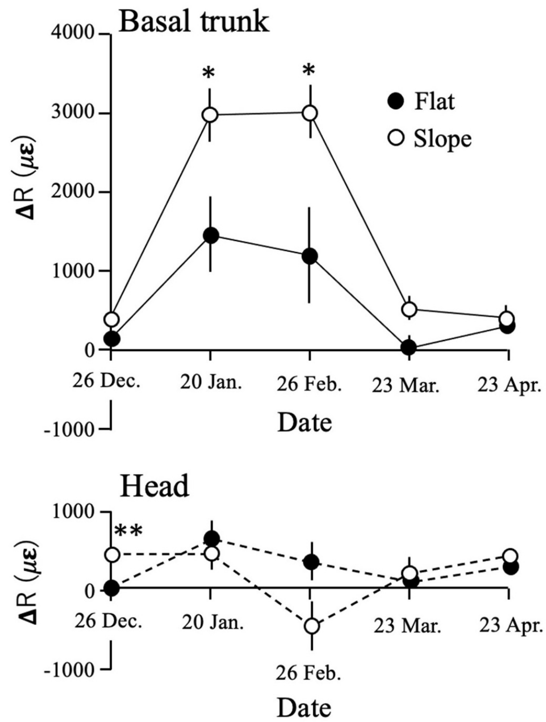

Fig. 2: Transition of ΔR (με) in basal trunk and head of 'Gewürztraminer' grapevine in flat and slope zones in 2019-2020. ** and * represents significance at 1 % and 5 % of student's t-test among cultivars respectively (one-side test, n = 5).

Comparison between 'Gewürztraminer' and 'Kerner' (Experiment 2): The distortion in the basal trunk and head of 'Gewürztraminer' and 'Kerner' grapevines in the flat zones was measured using the strain gauge's value, ΔR (Tab. 4). The effect of cultivar was not significant in all months. However, there was some tendency for the ΔR values in basal trunk to be larger than that in the head in February, March and April. Additionally, the interaction between cultivar and position was also detected slightly in February.

The transition of distortion, in the basal trunk and head of 'Gewürztraminer' and 'Kerner' grapevines in the flat zones is shown in Fig. 3. The distortions in the basal trunk

Table 3

Distortion in each part of 'Gewürztraminer' grapevine in flat and slope zones

Zone (Z)		ΔR ($\mu\varepsilon$)									
		26 Dec.		20 Jan.		26 Feb.		23 Mar.		23 Apr.	
Flat		93	(50)	1063	(277)	795	(339)	96	(74)	308	(44)
Slope		433	(53)	1737	(455)	1282	(615)	376	(126)	415	(85)
Position (P)											
Basal trunk		278	(69)	2232	(365)	2121	(437)	292	(126)	353	(90)
Head		248	(83)	568	(145)	-44	(235)	180	(97)	371	(41)
ANOVA	df										
Z	1	**		ns		ns		ns		ns	
P	1	ns		***		***		ns		ns	
Z x P	1	ns		*		*		ns		ns	

Numbers in parenthesis means S.E. df: degree of freedom.
***, ** and * represent significance at 0.1 %, 1 % and 5 % levels of ANOVA (n = 5), ns means not significant.

Table 4

Distortion in each part of two grapevine cultivars at flat zones

Cultivar (C)		ΔR ($\mu\varepsilon$)				
		26 Dec.	20 Jan.	26 Feb.	23 Mar.	23 Apr.
'Gewürztraminer'		251 (56)	747 (175)	565 (177)	348 (104)	143 (80)
'Kerner'		487 (308)	1699 (476)	1079 (563)	556 (405)	325 (125)
Position (P)						
Basal trunk		474 (316)	1606 (471)	1373 (394)	865 (240)	435 (93)
Head		265 (72)	840 (230)	272 (374)	39 (286)	32 (72)
ANOVA	df					
C	1	ns	ns	ns	ns	ns
P	1	ns	ns	†	†	**
C x P	1	ns	ns	†	ns	ns

Numbers in parenthesis mean S.E. df: degree of freedom.
** and † represents significance at 1 % and 10 % levels of ANOVA (n = 5), ns means not significant.

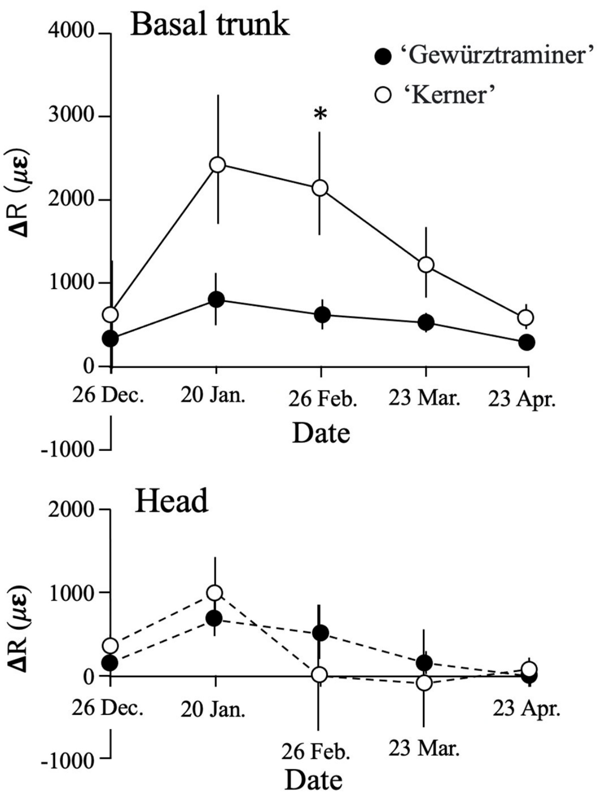

Fig. 3: Transition of ΔR (με) in basal trunk and head of two grapevine cultivars in flat zones in 2019-2020. * represents significance at 5 % of student's t-test among cultivars (one-side test, n = 5).

of 'Kerner' grapevines was significantly more than that of 'Gewürztraminer' in February.

Mortality of 'Gewürztraminer' and 'Kerner' grapevines in the flat zones from 2016 to 2020 was 9.6 (± 2.7) % and 12.8 (± 2.4) %, respectively. The averaged mortality of 'Gewürztraminer' grapevines over 5 years was significantly smaller than that of 'Kerner' (p value = 0.001, student's t-test (n = 5)).

Finally, the stress-wave velocity of each position in two grapevine cultivars cultivated in the flat zones is shown in Tab. 5. The difference of the stress-wave velocity among cultivars is detected at 10 % level of possibility, and that of 'Gewürztraminer' grapevines was slightly larger than that of 'Kerner'.

Discussion

T r i g g e r s o f s h o r t e r l i f e s p a n o f g r a p e v i n e s : The purpose of this study is to analyze the impact of snowfall on the short life span of the grapes, which is an issue that vineyards in snowy regions of Hokkaido have faced. After a survey of the relationships between snowfall and vineyard, some researches demonstrated there was no effect on viticulture (Biancotti *et al.* 2006) or it had beneficial effect of precipitation in the form of snow (Caprio and Quamme 2002). But in actuality, some descriptions on the demerits of the 'short lifespan of grapevines caused by snow' in snowy vineyards were seen (Hirakawa *et al.* 2014, Nagata *et al.* 2014, Saltanat 2020). If the longevity was shorter than in non-snowy regions, the cycles of renewal in vineyards was faster, meaning big costs to the grape farmers for labor and other costs (JVA 2020).

It was shown that poor drainage due to heavy clay soil layers can cause shorter life span of grapevines in the Sorachi district of Hokkaido and that treatment with a subsoiler can improve the physical condition of the vineyard soil (Hirakawa *et al.* 2014). Also, the incorporation of organic matter into soil induced the grape's root elongation to a deep soil depth (Gaiotti *et al.* 2017). The improvement of soil porosity and drainage become a definite advantage for the growth of grapevines and their production (van Leeuwen *et al.* 2004, Ubalde *et al.* 2010). Therefore, the slopes have relative advantage for viticulture generally. However, the soil moisture in the slope zones was not so different from the flat zones. But actually, the phenomenon above ground must have some impact on the life span of grapevines in this experiment. A hypothesis that the declining snow cover on slopes or the stiffness of the grapevines also affects longevity was set up.

E f f e c t o f f l a t n e s s o f c u l t i v a t i o n a r e a o n s n o w d a m a g e : As described above, the cultivation of grapevines is better on slope zones because of soil drainage. However, snowmelt induces declining snow

Table 5

Stress-wave velocity at each position in two grapevine cultivars cultivated in flat zones

Cultivar	Stress-wave velocity (mm·s^{-1})								
	Basal trunk			Head			Cordon		
'Gewürztraminer'	1529	(169)	ns	1592	(137)	†	1606	(89)	ns
'Kerner'	1496	(116)		1460	(150)		1517	(140)	
P value			*0.385*			*0.052*			*0.130*

† represents significance at 10% of student's *t*-test (one-side test, n = 5), ns means not significant.

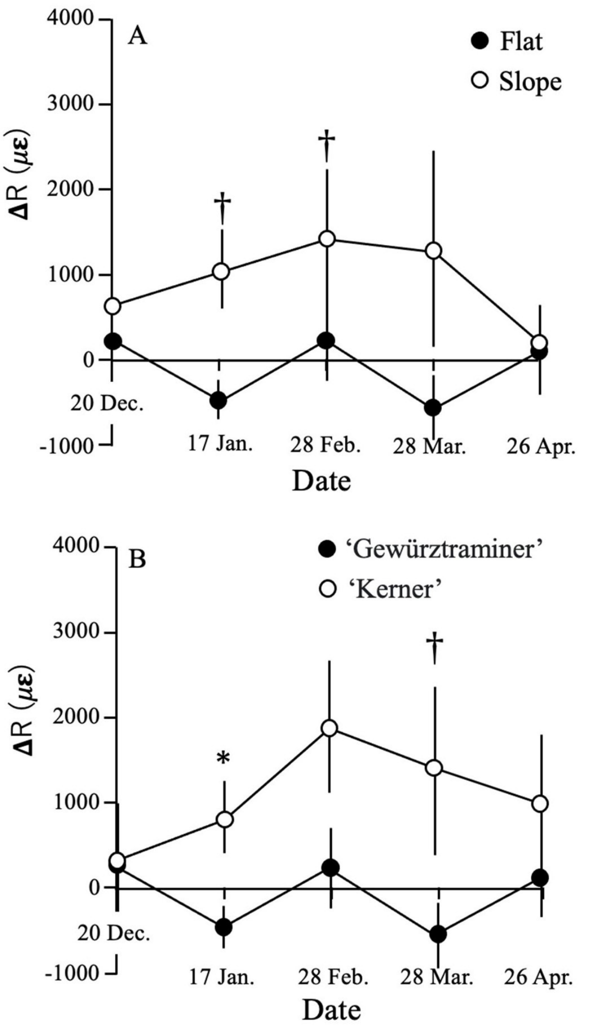

Fig. 4: Transition of ΔR (με) in basal trunk of two grapevine cultivars in flat zone (**A**) of 'Gewürztraminer' grapevine in flat and slope zones (**B**) in 2021-2022. * and † represents significance at 5 % and 10 % of student's *t*-test among cultivars respectively (one-side test, n = 3).

cover on slope zones in snowy regions (LATERNSER and SCHNEEBELI 2003, BENISTON 2012).

The result of this study showed significant differences in distortion between flat and slope zones with the phenomenon occurring mainly under seasons with deep snow cover (Fig. 2). This is clear evidence that snow induced the internal stress fluctuation itself. Furthermore, the mortality of grapevines in the slope zones exceeded that in the flat zones, though the results were from an analysis of just one cultivar.

In case of the differences in distortion of head position in December, the phenomenon was observed when the snow depth just reached to the height of the cordons (Fig. 1B), therefore the distortion may be generated by snow weight on the cordon. However, it is not clear why the phenomenon occurred in the slope zones specifically. It may be that snow depth is different in flat and slope zones and even different depending on which direction the face of the slope is facing.

Next, as for the differences in distortion of the basal trunk position in January and February, the phenomenon occurred under the snow unlike the head (Fig. 1C). The air temperature did not raise through the duration, and apparently, the snow did not shift in a crosswise direction, but the slightly declining snow cover may occur in the slope zones, and then the motion of snow possibly induced the distortion of the basal trunk. The small distortion of grapevines in the flat zones may be induced by the weight of the snow pushing the leaning trunk down. As a result, the grapevines cultivated in the slope zones suffered twice the distortion as those in the flat zones for more than two months. Therefore, the possibility that this status is linked to a 5 % increase in the mortality of grapevines cannot be denied.

Effect of the stiffness of grapevine on snow damage: As described above, the grapevines may be loaded with physical stress from the weight of the snow itself and from continuous snow shift. If it is reliable, the stiffness of grapevines also reflects the magnitude of distortion. Unfortunately, a previous study about the stiffness of wine grapevines could not be found. So, two grape cultivars whose stiffness are instinctively different based on the opinion of the vineyard managers from when they train the vines to wires in spring, were used. Based on their experience, 'Gewürztraminer' is harder than 'Kerner' relatively. The two unique cultivars were investigated where no slope effect exists.

The distortion value of 'Kerner' exceeded that of Gewürztraminer' in basal trunk in February (Fig. 3). The mortality of 'Kerner' was larger than that of'Gewürztraminer'. The results that a larger distortion linked to a higher mortality was similar to Experiment 1. The results also suggest that the physical stress at the basal trunk is closely linked to the damage in the grapevines in Experiment 1 and 2.

This study treated the differences in stiffness of grapevines among cultivars. Stress-wave velocity can be used with Young's modulus estimation. A large value means it does not deform easily and a small value means it does. In other words, it represents the stiffness of a material (Namie *et al.* 2013). The stress-wave velocities of grapevines did not significantly fluctuate between cultivars, however, it seems to be a trend that the values of 'Kerner' were smaller than that of 'Gewürztraminer' with a focus on the head position (Tab. 5). The result coarsely indicates that the grapevine of 'Gewürztraminer' is more rigid, and the grapevine of 'Kerner' is more flexible, or 'softer'. Trees and standing trees with high values of stress wave-velocity generally have a low tendency to warp and provide a hard and stable lumber (Floyd and Huang 2007). The result suggested that the larger distortion consequently occurred in the tissue of softer 'Kerner' because it was easily warped by snow weight and shift. The softness may occasionally be accompanied with plasticity, and the plasticity seemed to mitigate the physical stress of snow by turning aside. However, the softness seemed to accompany severe damage in that case. Further study is necessary to assess the persistence of grapevines multi-directionally, and to analyze the causal relationship between the natural material's characteristics and damage from snow.

What position on the grapevine easily suffers physical stress from snow?: As described above, through the two experiments, the tendency can be observed that the distortion of grapevines was increased in the basal trunk more than in the head (Tabs 3 and 4), and that the magnitude of the distortion becomes larger in grapevines buried in snow (Figs 2 and 3). The direction of 'Gewürztraminer's furrow in the slope zones coincided with the cordon's elongation, and also coincided with the direction towards the valley's bottom. These results suggested that the sum of weights of the cordon itself and the shifting power of declining snow cover with snow melt mounted on the basal trunk. It is not strange that the laceration of vessel or sieve tubes, and the collapse of the supporting structure from the wounding by physical stress occurred. Actually, some grapevines have wounding with a part of the basal trunk's tissue being dead (Fig. S1 A and B). The snow damage of the basal trunk may shorten the life span, or make it more susceptible to contracting diseases from the wounded area which may contribute to an early death. The wounds are the most important points of entry for wood colonizing fungal pathogens, even in creeping grapevines (Mondello *et al.* 2018). There was a tendency for there to be a larger distortion for grapevines in the less snow-covered year than the more snow-covered year (Figs 2, 3 and 4, Tab. S2). The temperature of winter in 2019-2020 was slightly higher than that in 2021-2022, especially in the transition of the averaged minimum temperature (Fig. S2). The snow pile may become heavier in relative warmer climate, however verification is required about the possibility of whether a less snow-covered situation induces a heavier physical stress for grapevines.

Another source of stress may be from the typical training method accompanied with the cordon operation moving up and down every year, which must be a cause of physical damage of the basal trunk. Especially in spring, the grapevines are forced to recover to the natural 'single cordon' shape (Fig. 1D) from the dropping cordon shape. The effect of the operation was not analyzed, however, the physical motion may add to the stress already received from the snow.

Conclusions

Considering grapevine cultivation in Hokkaido with severe cold in winter, the Sorachi district as a snowy region has a merit that grapevines can pass the winter at near zero degrees in the snow pile. On the other hand, this region has the demerit that grapevines suffer from physical stress by the snow pile as observed in this study. This study still does not remove all ambiguity for the interpretation that the snow stress is a main factor affecting the short life span of grapevines in snowy districts. However, the relationships between the distortion of grapevines and the mortality were consistent in the different experiments 1 and 2 in this study. In slope zones in a snowy district, the declining snow cover must occur in every winter, and the damage rate may be faster than the recovery rate and the trend of reducing their longevity may be remarkable in the softer cultivars especially. Therefore, it can be suggested that the planting of cultivars with hard trunks may be better for the longer life span of grapevines in slope zones inclined at about 10 degrees or more.

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Conflicts of Interest

All authors declare there are no conflicts of interest that would prejudice the impartiality of this scientific work.

Author Contributions

Yutaka Jitsuyama conceived the study, designed and supervised the research, analyzed the data, and wrote the article with the support of all authors; Yutaro Kita performed a part of the measurements; Keita Arakawa and Takashi Suzuki supervised the research and reviewed the manuscript. All authors are in agreement with the manuscript.

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