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Corresponding Author:	Eiichi Obataya Graduate School of Life and Environmental Sciences Tsukuba, Ibaraki Japan
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Graduate School of Life and Environmental Sciences
Corresponding Author's Secondary Institution:	
First Author:	Hikaru Akahoshi
First Author Secondary Information:	
Order of Authors:	Hikaru Akahoshi
	Eiichi Obataya
Order of Authors Secondary Information:	
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Effects of wet-dry cycling on the mechanical properties of *Arundo donax* L. used for the vibrating reed in woodwind instruments

Hikaru Akahoshi・Eiichi Obataya

Abstract

The effects of wet-dry and moist-dry cycling on the mechanical properties of reed (*Arundo donax* L.) were investigated. Because water-soluble extractives were lost through wetting, the reed shrunk in its tangential direction, and its dynamic Young's modulus and loss tangent decreased during wet-dry cycling. On the other hand, the reed swelled in its radial direction because of the recovery of cell collapse, which had been induced by drying from a green state. Consequently, the resonant frequency of the reed monotonically increased during wet-dry cycling, whereas no clear trend was seen in bending rigidity. During moist-dry cycling, the equilibrium moisture content of reed decreased slightly. Such a reduction in hygroscopicity was attributed to the aggregation of deliquescent extractives. The changes in the dimensions and vibrational properties of the reed specimens during moist-dry cycling were qualitatively similar to those during wet-dry cycling. These results suggest that the practical performance of woodwind reed changes irreversibly during continuous usage.

Keywords: *Arundo donax* L., Vibrational properties, Water-soluble extractives, Cell collapse, Reed

Introduction

Giant Reed (*Arundo donax* L.) is traditionally used for the vibrating plates (reeds) of woodwind instruments. The reed is the most important part for musicians because it determines the quality of tone, pitch, and controllability of the instrument (Obataya 1996a). Musicians often claim that the quality of reed changes irreversibly by continuous playing (Stein 1958; Obataya 1996a). However, such irreversible effects of playing on reed quality have not been thoroughly studied.

As the reed is vibrated between human lips, possible reasons for the irreversible change in reed quality are aging, mechanical stimulation by forced vibration, and repeated wetting and air-drying. According to Kohara (1954), the mechanical properties of wood change through aging over a few hundred years. However, reeds are only used for a few months in many cases (Obataya 1996a). Therefore, the aging effect is not likely responsible for the irreversible change discussed here. Hunt and Balsan (1996) reported that the loss tangent ($\tan\delta$) of wood decreased approximately 5% and its resonant frequency increased approximately 0.3% with 48 h of forced vibration at 90% relative humidity. However, those changes are much smaller than those due to water extraction, as described below.

The reed contains large amounts of water-soluble extractives consisting of monosaccharides in parenchyma cells. When the extractives are lost, the dynamic Young's modulus (E') and $\tan\delta$ of reed decrease approximately 8% and 56%, respectively (Obataya et al. 1999). As the extractives are water-soluble, they are lost through repeated wetting during reed usage. When the reed is exposed to wet-dry cycles, the recovery of cell collapse should also be considered. It has been reported that significant cell collapse is induced in the parenchyma cells of the reed during drying by the reed manufacturer, but the collapsed cells can be recovered by alternate moistening and drying (Obataya 1996b; Obataya et al. 2004). Such recovery, i.e., dimensional change, may indirectly affect the performance of reed, because the resonant frequency and flexural rigidity of the reed depend on its dimension. Moreover, Esteban et al. (2005) reported that the hygroscopicity of wood is reduced by repeated moistening and drying. Therefore, this seasoning effect may be the result of frequent wet-dry cycles of the reed.

In this paper, we investigate the effects of wet-dry and moist-dry cycles on the mechanical properties and dimensions of reed to explain the irreversible changes that take place during the practical use of the reed in a woodwind instrument.

Materials and methods

Materials

We used fifteen internodes of *Arundo donax* L., which were harvested and dried for clarinet reeds in Antibes, France. Specimens (108 total) measuring 70 mm in length (longitudinal, L) × 5 mm in width (tangential, T) × 0.5 mm in thickness (radial, R) were prepared from both the peripheral and inner portions of the internodes. Three and five representative specimens from each of the low, medium, and high-density specimens were selected, based on their average density values, for wet-dry cycle testing and moist-dry cycle testing, respectively.

Wet-dry cycle testing

The specimens were dried over P_2O_5 under vacuum and their absolute dry mass (m_0) values were measured. The specimens were then equilibrated at 25 ºC and 60% RH for more than 3 days to determine their mass and vibrational properties. Next, the specimens were soaked in water under reduced pressure for 2 h (wetting), followed by drying at 25 ºC and 60% RH until mass equilibrium was reached. The vibrational properties of those specimens were then determined at 25 ºC and 60% RH. This wet-dry process was repeated 14 times. Finally, the specimens were soaked in water for 1 week to remove the remaining water-soluble extractives and their absolute dry mass (m_{e0}) values were determined.

Moist-dry cycle testing

The mass and vibrational properties of the specimens were measured at 45%, 51%, and 60% RH. Next, the specimens were moistened at 25 ºC and 100% RH in a desiccator under reduced pressure for 1 day (moistening). The specimens were then dried at 25 ºC and 60% RH for 1 day (drying) to determine their mass and vibrational properties. The moistening and drying times were enough to achieve mass equilibrium of the specimens. That moist-dry process was repeated 6 times. Finally, the specimens were oven-dried at 105 ºC for 1 day to measure their absolute dry mass. Six specimens were soaked in water for 1 week to remove the water-soluble extractives prior to moist-dry testing.

Measurement of vibrational properties

The E' and $\tan\delta$ of the specimens in their fiber direction were determined by the cantilever method. A brass clamp held one end of the specimen and the other end was tapped using a small glass ball. The deflection of the specimen was detected using a laser displacement sensor. The E' and $\tan\delta$ values

were calculated from the resonant frequency of the first mode and the decrement curve, respectively.

Microscopic observation

Short cylinders (~14 mm long) were cut from the internodes, and the cylinders were split into 6 pieces along the grain. The microtomed cross sections of those pieces were then observed before wet-dry cycling, after 10 wet-dry cycles, and after steaming under saturated water vapor, at ~85ºC for 1 h.

Results and discussion

Effects of wet-dry cycling

Figure 1 shows the change in air-dry mass (m) of three specimens with low, medium and high densities during wet-dry cycling. Three representative specimens were selected to understand the behavior of the reed. The m decreased and approached its asymptotic value within 14 wet-dry cycles. That reduction in mass was largely due to the loss of water-soluble extractives. When the m value was divided by the air-dry mass of the extracted specimen (m_{e0}), excellent correlation (R = 0.998) between m/m_{e0} and extractive content (EC) for all specimens was seen before wet-dry cycle testing. Thus, the EC value was calculated from m/m_{e0}. Figure 2 shows the changes in EC with the number of wet-dry cycles. The low-density specimens contained more extractives than the higher density specimens did because the extractives are primarily found in parenchyma cells; the density of parenchyma cells is lower than that of the other tissues, such as bundle sheaths (Obataya et al. 1999). The EC values reached 0.05 within several wet-dry cycles, irrespective of the initial EC values. This fact suggests that a large amount of water-soluble extractives is lost through wetting by the musicians' mouths.

Figure 3 shows the changes in thickness (radial direction, R) and width (tangential direction, T) of the three specimens during wet-dry cycling. The thickness gradually increased with the number of wet-dry cycles. A similar trend was seen with the other specimens tested. The degree of swelling did not depend on density. The increase in thickness (radial expansion) can be explained by the recovery of cell collapse. Figure 4 displays the images of the specimen cross sections before and after wet-dry cycling. Before wet-dry cycling, cell collapse was observed in the parenchyma cells (Fig. 4a). During wet-dry cycling, the collapsed cell wall was plasticized with moisture, while additional collapse did not occur because the cell lumina were not completely filled with free water.

Consequently, the collapsed cells gradually recovered their original shape (Fig. 4b). The shape recovery of the cells is completed by steaming (Fig. 4c), because the cell wall is softened at higher temperatures (Obataya et al. 2004). Thus, the increase in thickness with the number of wet-dry cycles is due to the recovery of cell collapse remaining in the reed. The degree of radial expansion depends on that of the initial collapse caused by drying from its green state, rather than the density and volume fraction of the parenchyma cells.

The width (w) of the specimens remained unchanged or slightly decreased during the wet-dry cycles. The decrease seems to be normal tangential shrinkage, due to the loss of extractives. Although little is known about the anisotropic shrinkage of reed, the shrinkage of bamboo has been well researched. The ratio of tangential and radial shrinkage of bamboo is 1.2 for the outer part and 1.0 for the inner part (Nakato 1959). Thus, we assumed the following: (i) The volume of cell lumen does not change. (ii) The entire amount of the extractives exists in the cell wall. (iii) The cell wall shrinks because of the loss of extractives. (iv) The shrinkage in radial (thickness) and tangential (width) directions are the same, whereas the reed does not shrink in the longitudinal (length) direction. Although the location of the extractives is still unclear, it has been proven that the extractives of bamboo are located in the cell wall. The extractives are not removed from green bamboo, whereas the extractives are easily lost by soaking in water when the bamboo is dried and the cell wall membrane is broken (Suzuki 1953). This fact suggests that the extractives of reed are located in the cell walls in the reed's green state. Based on the assumptions above, the tangential shrinkage (change in width) was calculated from the loss of extractives using the following equation,

$$\frac{w-w_0}{w_0} = -1 + \sqrt{1 + \frac{m-m_0}{\rho_e V_0}}$$

where the subscript, 0, represents the value before wet-dry cycling, V is the volume of the specimen, and ρ_e is the density of the extractives. Since both the extractives and the hemicellulose consist of saccharides of low molecular weight, we used 1500 kg/m^3 for ρ_e (Bosshard 1974). As the calculated values agreed well with the experimental values, the tangential shrinkage during wet-dry cycling was attributed to the loss of extractives.

Figure 5 shows the change in E' of the reed specimens as a function of the number of wet-dry cycles and EC. The E' decreased with the number of wet-dry cycles. It has been suggested that the E' is significantly reduced with the removal of extractives, but the E' is recovered by the introduction of sugar, which is similar to natural extractives (Obataya and Norimoto 1999). Therefore, the reduction in E' with the number of wet-dry cycles is due to the loss of extractives. Changes in $\tan\delta$ of the reed specimens are shown in Fig. 6. The $\tan\delta$ decreased with the number of wet-dry cycles. The reduction

in tanδ is also attributed to the loss of extractives. The changes in tanδ are related to those changes in EC. The low-density specimen showed greater reductions in E' and tanδ than the higher density specimens did because the low-density specimen contains larger amount of extractives.

For musicians, the rigidity of the reed (vibrating plate) is an important factor affecting its performance. Since the bending rigidity ($E' I$) of reed is the product of E' and the second moment of area (I), we need to consider the radial expansion due to the recovery of cell collapse. Figure 7 shows the changes in $E'I$ and resonant frequency (f_r) of the specimens with the number of wet-dry cycles. The changes in $E'I$ are influenced by the change in thickness and E'. In many cases, the $E'I$ sharply decreased after the first wet-dry cycle because of the loss of extractives, which is related to a significant reduction in E'. In some specimens, the $E'I$ then increased with the number of wet-dry cycles. Such an increase in $E'I$ is due to thickening, which results in an increase in I. On the other hand, the f_r values are proportional to the square root of $E'I/m$, and the decrease in m due to the loss of extractives was large enough to negate the drop in $E'I$. Consequently, the f_r increased with the number of wet-dry cycles, as shown in Fig. 7b.

Effects of moist-dry cycles

Figure 8 shows the changes in the equilibrium moisture content (MC) of non-treated and extracted specimens during moist-dry cycling. The MC of both non-treated and extracted specimens increased after the first moist-dry cycle. That increase in MC was due to moisture sorption hysteresis: the initial MC was determined during adsorption, whereas the MC was determined during desorption, after the first moist-dry cycle. After the first moistening, the MC of the extracted specimens remained unchanged, but that of the non-treated specimens gradually decreased during moist-dry cycling, irrespective of their densities. This fact suggests that the extractives affected the reduction in MC during moist-dry cycling. Since the extractives are deliquescent compounds, it is suggested that the extractives were deliquesced and exited from the cell wall during moistening. The higher MC in the non-treated specimens is due to the loss of extractives from the cell wall, because such “free” extractives show higher hygroscopicity than those within the cell wall particularly at high RHs (Obataya and Norimoto 1995b). On the other hand, the hygroscopicity of the free extractives might be gradually reduced by their aggregation in the cell lumen. This phenomenon - the consolidation of deliquesced sugar - is known as “caking” in the food industry (Mathlouthi and Rogé 2003).

According to Esteban et al. (2005), the hygroscopicity of wood is reduced with repeated moist-dry cycles. However, such a seasoning effect is less significant than the effects of the extractives in the present study, because the MC of the extracted specimens remained almost unchanged.

Figure 9 shows the change in thickness of the non-treated specimens with the number of

moist-dry cycles. The thickness of the specimens increased sharply with the first moistening. This increase cannot be explained by the slight increase in MC due to moisture sorption hysteresis, because a 2% increase in MC is projected to cause only a 0.4% increase in thickness. Thus, the increase in thickness can be attributed to the recovery of cell collapse, as seen during wet-dry cycling.

Changes in the E' and tanδ of non-treated specimens are shown in Fig. 10. After the first moist-dry cycle, both E' and tanδ remained constant or slightly decreased. As the E' and tanδ depend strongly on MC, those values are plotted against MC in Fig.11. Before moistening, the E' and tanδ decreased with increasing MC, as reported in our previous article (Obataya and Norimoto 1995a). However, the E' and tanδ significantly decreased after the first moistening, and continued to decrease during the subsequent moist-dry cycles. Such changes in E' and tanδ were qualitatively similar to those due to wet-dry cycling, which is related to the loss of extractives. This suggests that moist-dry cycling results in the movement of the deliquesced extractives from the cell wall to the cell lumen. As in the case of wet-dry cycling, $E'I$ fluctuated and f_r increased during moist-dry cycling, but the effects of moist-dry cycling were less significant than those of wet-dry cycling.

Irreversible changes in practical performance of woodwind reeds

A woodwind reed is vibrated by exhaled air. Because of coupled vibration of the air column with the reed, its resonant frequency affects the pitch of the instrument. Consequently, the most important parameters for woodwind reeds are tanδ, $E'I$, and f_r. The transient of vibration is affected by tanδ (French 1971). As a larger tanδ value results in more rapid excitation of vibration, the reed responds more quickly to the exhaled air and the acoustic feedback from the air column. On the other hand, the $E'I$ is related to the amplitude of vibration of the reed, and a lower $E'I$ value enables easier vibration. The f_r of reed determines the resonant frequencies of coupled vibrations with the air columns, or the pitch of instruments.

Here we discuss the changes in the performance behavior of the reed due to playing, i.e., intermittent wetting and moistening. In the beginning of its use, the reed becomes less responsive but more easily vibrated, because both tanδ and $E'I$ are reduced. For the most part, those changes are irreversible changes, such as the loss of extractives and recovery of cell collapse; the reduced tanδ and $E'I$ cannot be recovered by scraping the reed. The tone pitch of the instruments is predicted to increase due to the increase in f_r. The pitch can be recovered by scraping the reed, but scraping leads to significant reduction in $E'I$. Wetting and moistening induce irreversible changes in reed properties. Thus, musicians should avoid prolonged playing of the instrument to maintain the initial performance of reed.

Conclusion

The dynamic Young's modulus and loss tangent of reed (*Arundo donax* L.) specimens decreased with the number of wet-dry cycles because of the loss of water-soluble extractives. The reed specimen thickness gradually increased (radial expansion) with the number of wet-dry cycles, due to the recovery of cell collapse. A number of specimens showed a decrease in width (tangential shrinkage) with the number of wet-dry cycles, due to the loss of extractives. The bending rigidity of the specimens sharply decreased with the first wet-dry cycle, and then increased slightly or remained constant. The resonant frequencies of all specimens increased with the number of wet-dry cycles. These changes can be explained by the changes in the mass, thickness, and dynamic Young's modulus of the specimens.

It can be concluded that moist-dry cycling reduced reed hygroscopicity because the deliquescent extractives exited the cell wall during moistening and aggregated in the cell lumen during drying. The moist-dry cycles also induced the swelling due to the recovery of cell collapse. However, changes in vibrational properties due to moist-dry cycling were less significant than those changes due to wet-dry cycling.

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Figure Captions

Fig. 1 Change in mass of *Arundo donax* L. specimens with the number of wet-dry cycles. *Circles*, specimens of ρ = 390 kg/m^3; *triangles*, specimens of ρ = 483 kg/m^3; *squares*, specimens of ρ = 563 kg/m^3

Fig. 2 Change in extractives content (EC) of *Arundo donax* L. specimens with the number of wet-dry cycles. See Fig. 1 for legends.

Fig. 3 Changes in thickness (*t*) and width (*w*) of *Arundo donax* L. specimens during wet-dry cycling. *Filled plots*, thickness; *open plots*, width; *circles*, ρ = 390 kg/m^3; *triangles*, ρ = 483 kg/m^3; *squares*, ρ = 563 kg/m^3

Fig. 4 Cross section of an *Arundo donax* L. specimens (**a)** before wet-dry cycling, (**b)** after 10 wet-dry cycles, and (**c)** after steaming. Vascular bundles (v) and parenchyma cell (p) are shown. Circles show typical recovery of a cell collapse. Scale bar, 200 μm; R, radial direction; T, tangential direction.

Fig. 5 Change in dynamic Young's modulus (E') of *Arundo donax* L. specimens during wet-dry cycling plotted against (**a**) number of wet-dry cycles and (**b**) extractives content (EC). See Fig. 1 for legend.

Fig. 6 Change in loss tangent ($\tan\delta$) of *Arundo donax* L. specimens during wet-dry cycling plotted against (**a**) number of wet-dry cycles and (**b**) extractives content (EC). See Fig. 1 for legend.

Fig. 7 Changes in (**a**) bending rigidity ($E'I$) and (**b**) natural frequency (f_r) of *Arundo donax* L. specimens during wet-dry cycling. See Fig. 1 for legend.

Fig. 8 Changes in moisture content (MC) of (**a**) non-treated and (**b**) extracted *Arundo donax* L. specimens during moist-dry cycling. *Circles*: specimens of low density; *triangles*: specimens of medium density; *squares*: specimens of high density.

Fig. 9 Change in thickness (t) of non-treated *Arundo donax* L. specimens with the number of moist-dry cycles. See Fig. 8 for legend.

Fig. 10 Changes in (**a**) dynamic Young's modulus (E') and (**b**) loss tangent ($\tan\delta$) of non-treated *Arundo donax* L. specimens with the number of moist-dry cycles. See Fig. 8 for legend.

Fig. 11 Changes in (**a**) dynamic Young's modulus (E') and (**b**) loss tangent ($\tan\delta$) of a non-treated *Arundo donax* L. specimen plotted against MC; its loss of moisture content (MC) was the largest, before and during moist-dry cycling. See Fig. 8 for legend.

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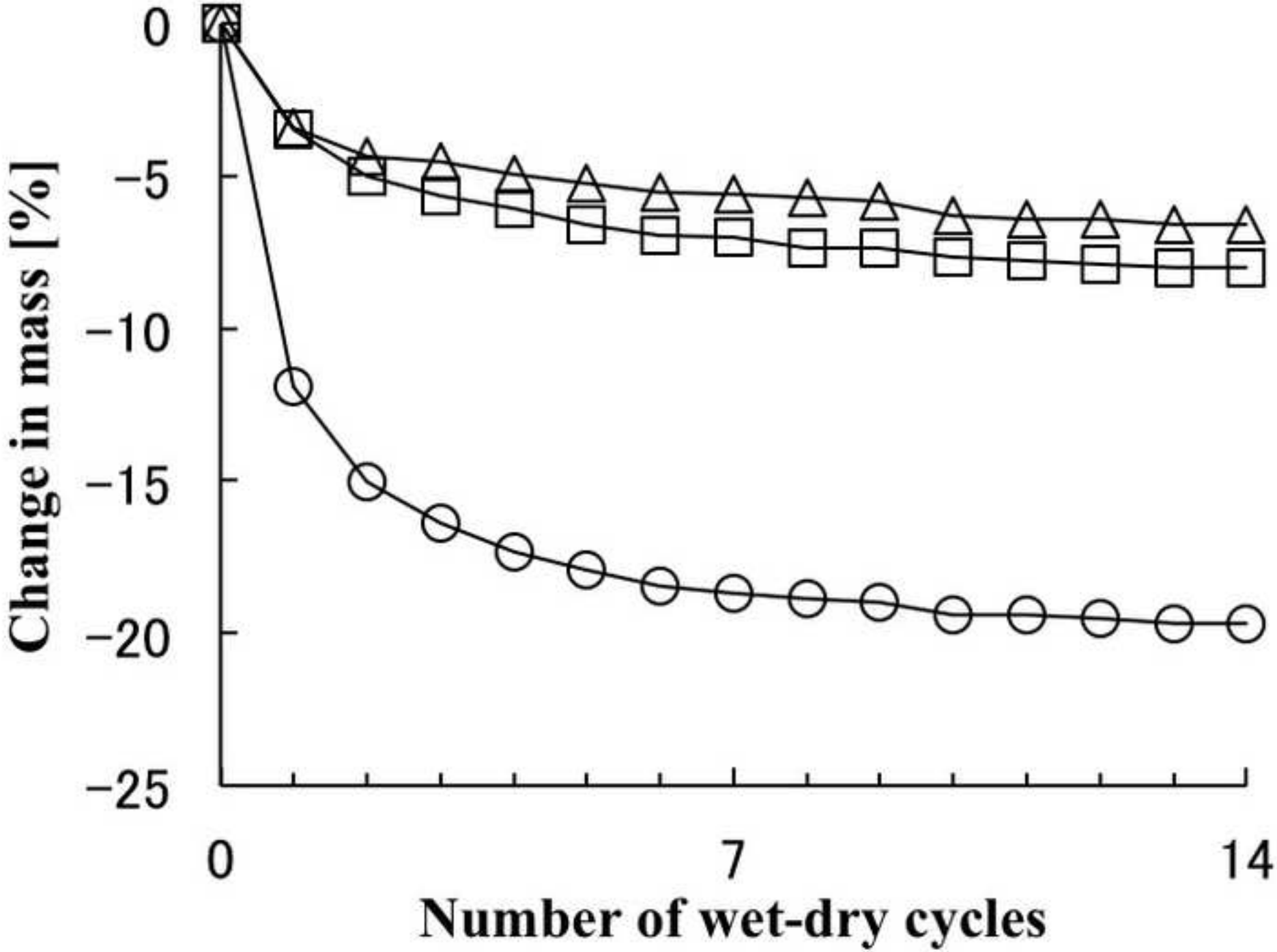

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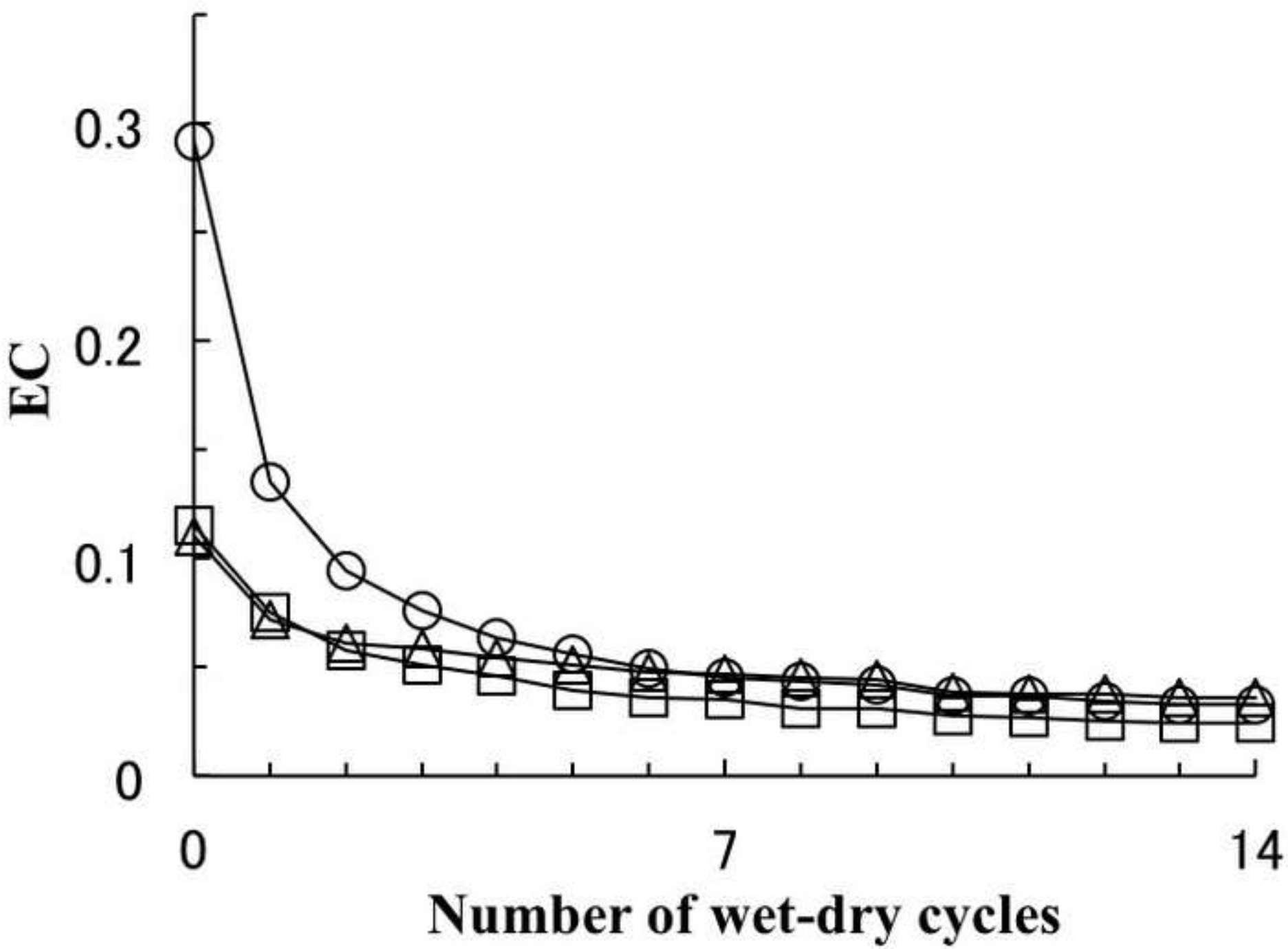

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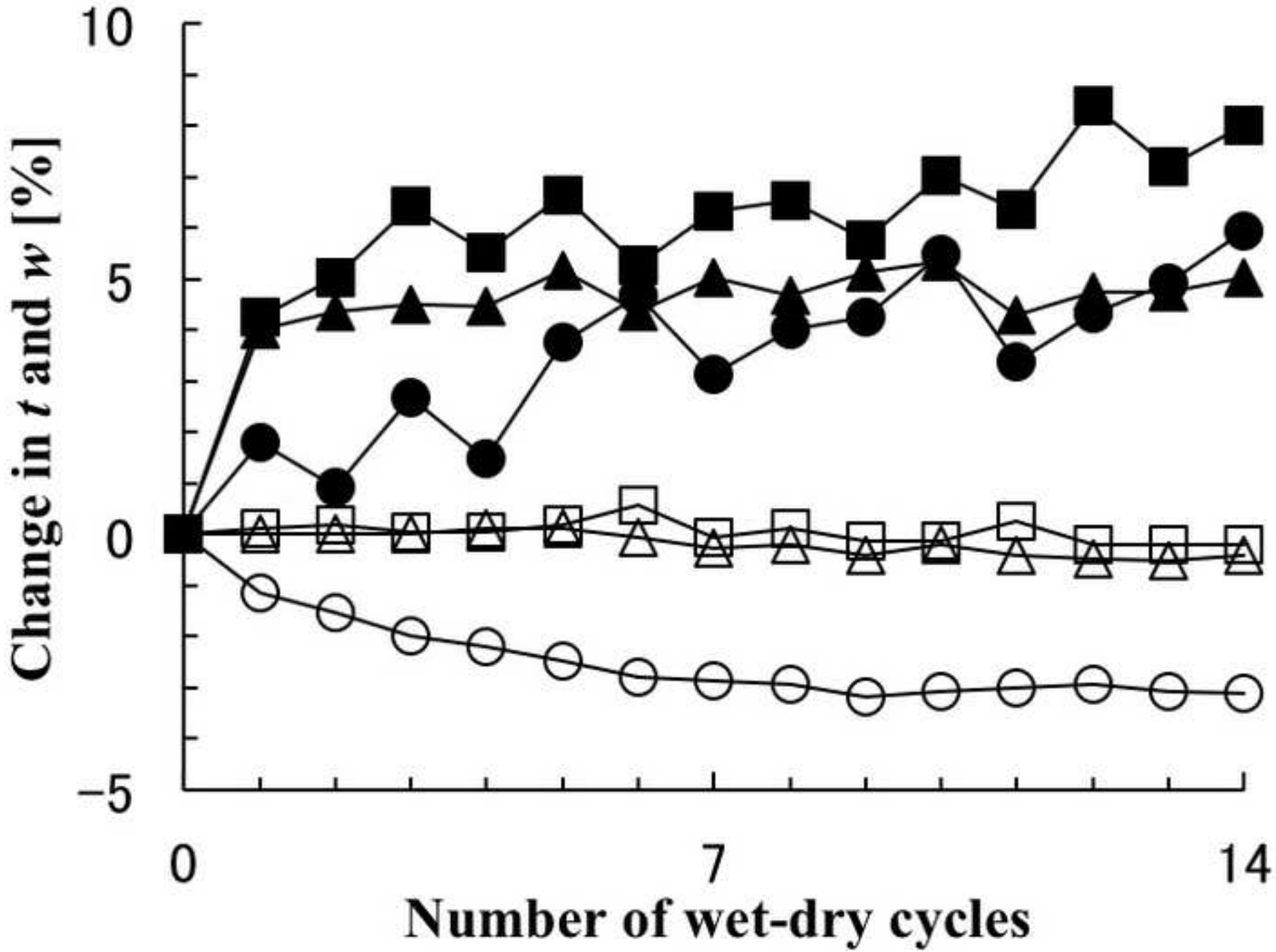

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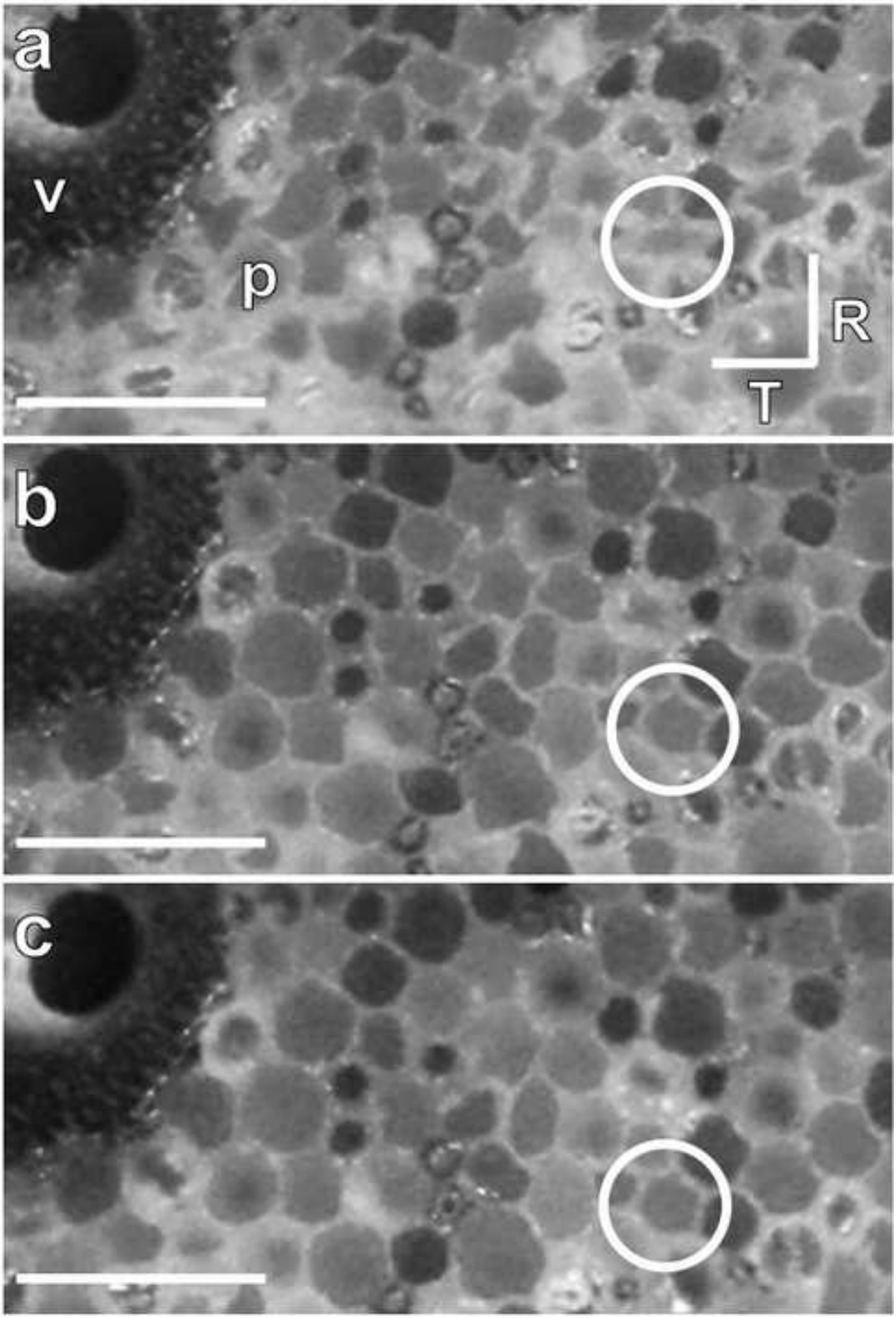

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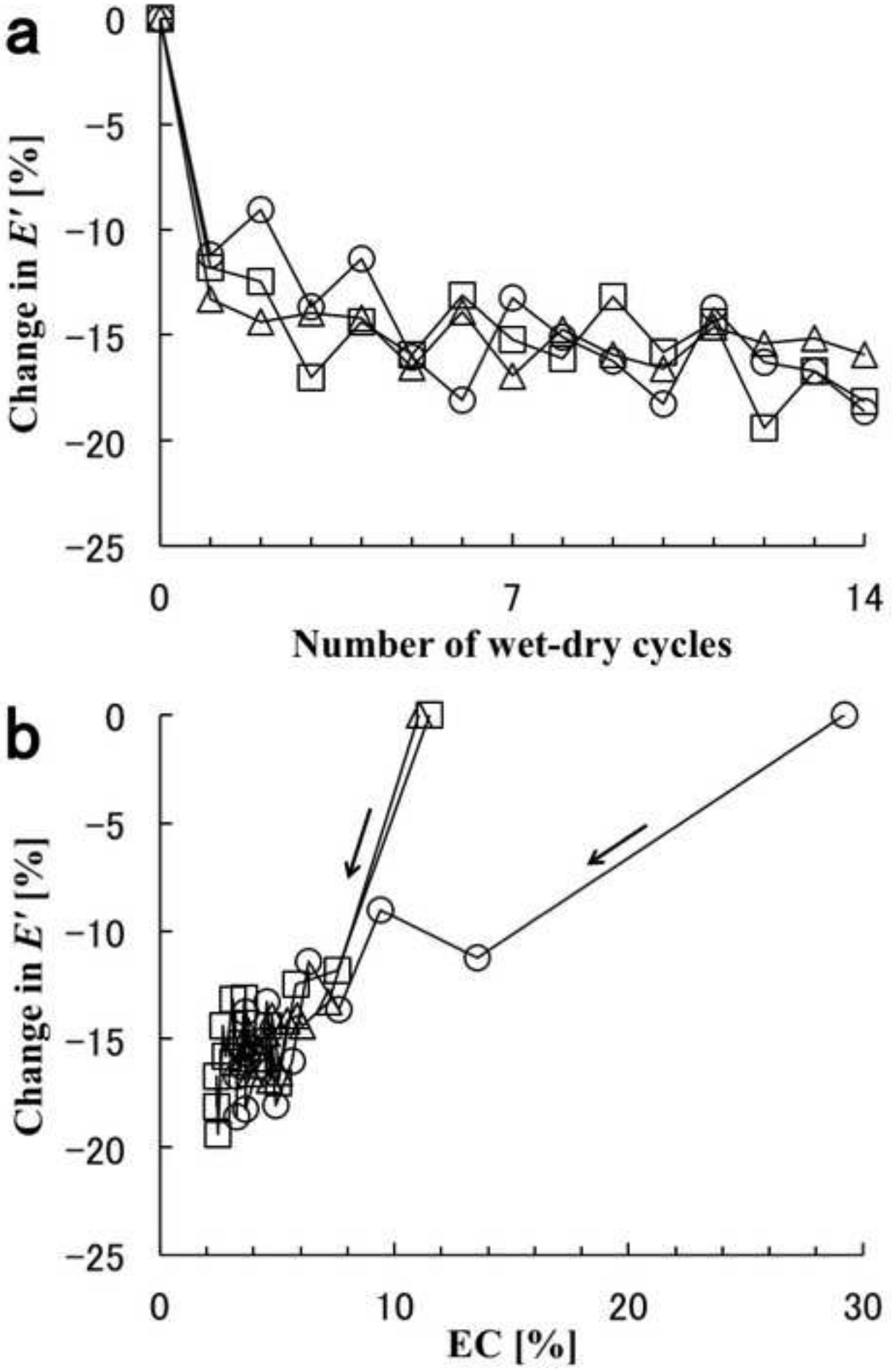

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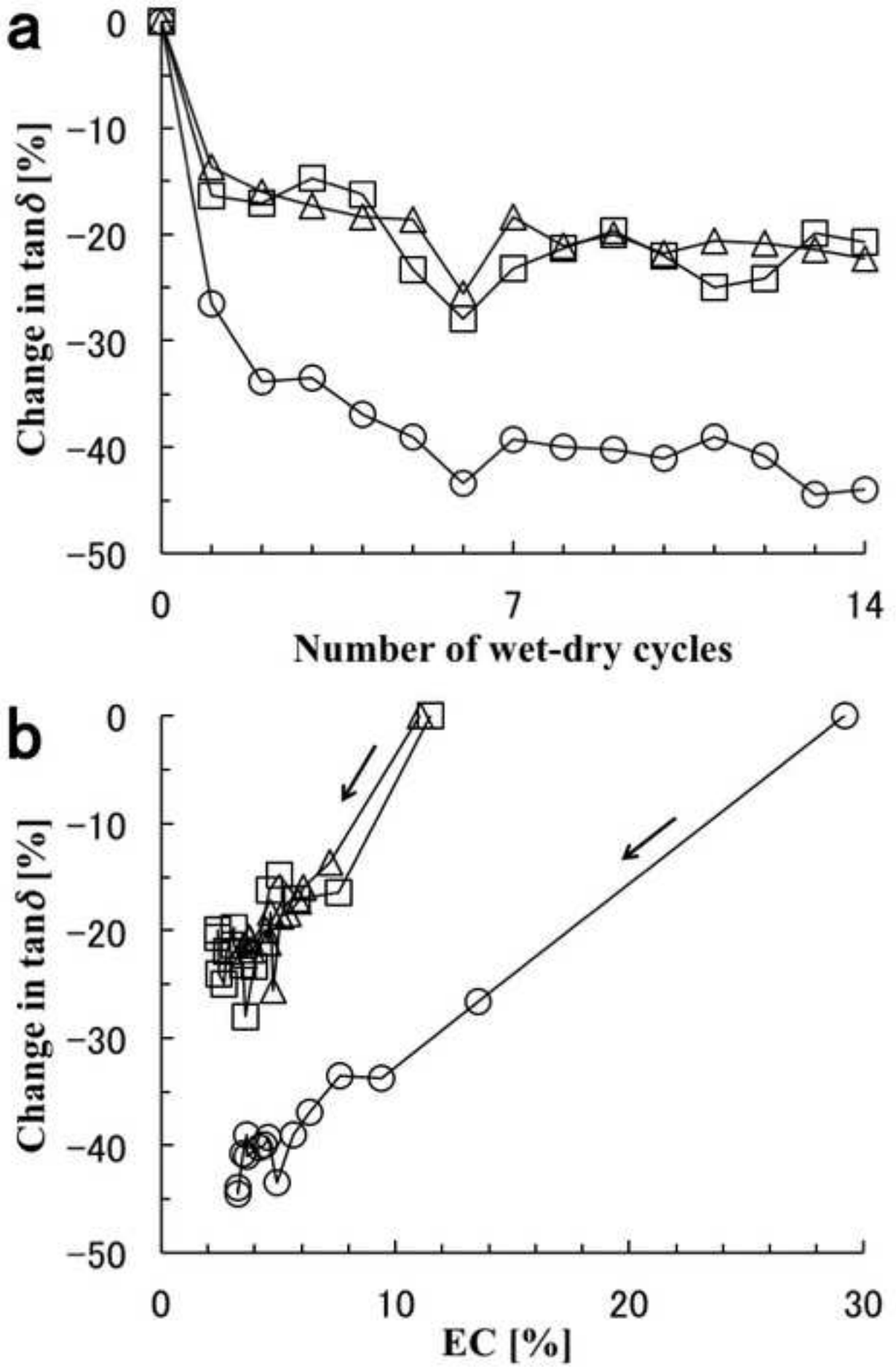

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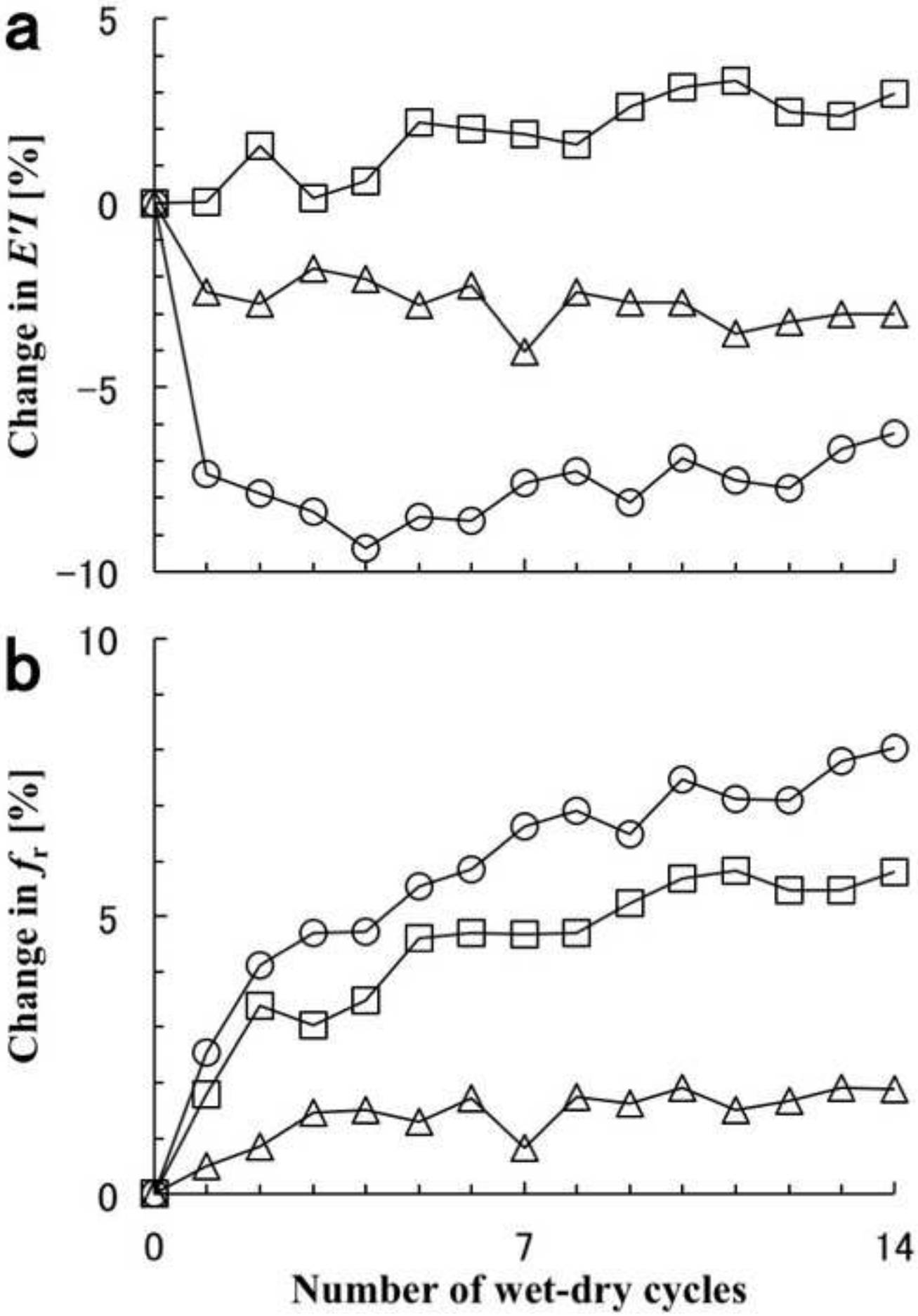

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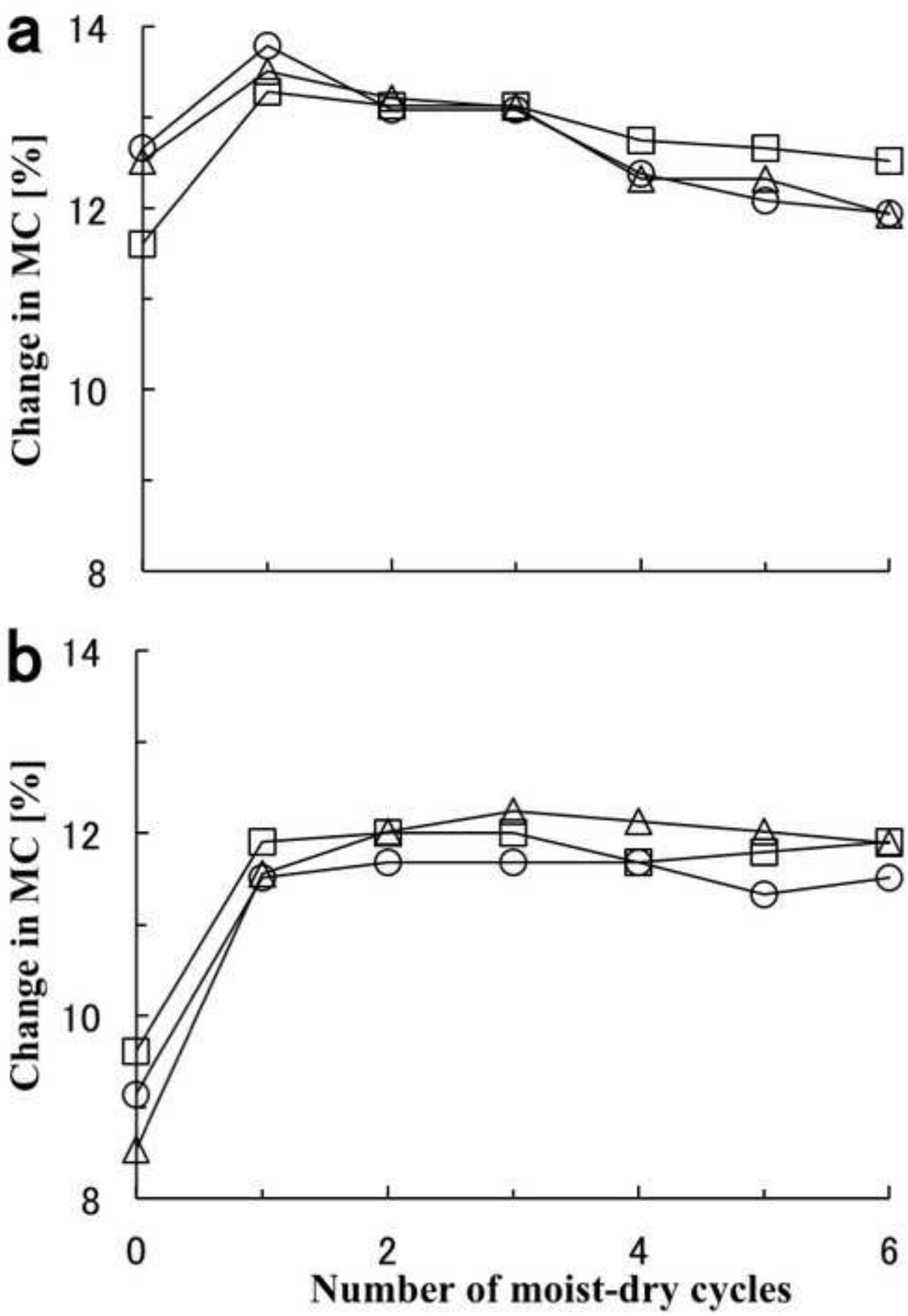

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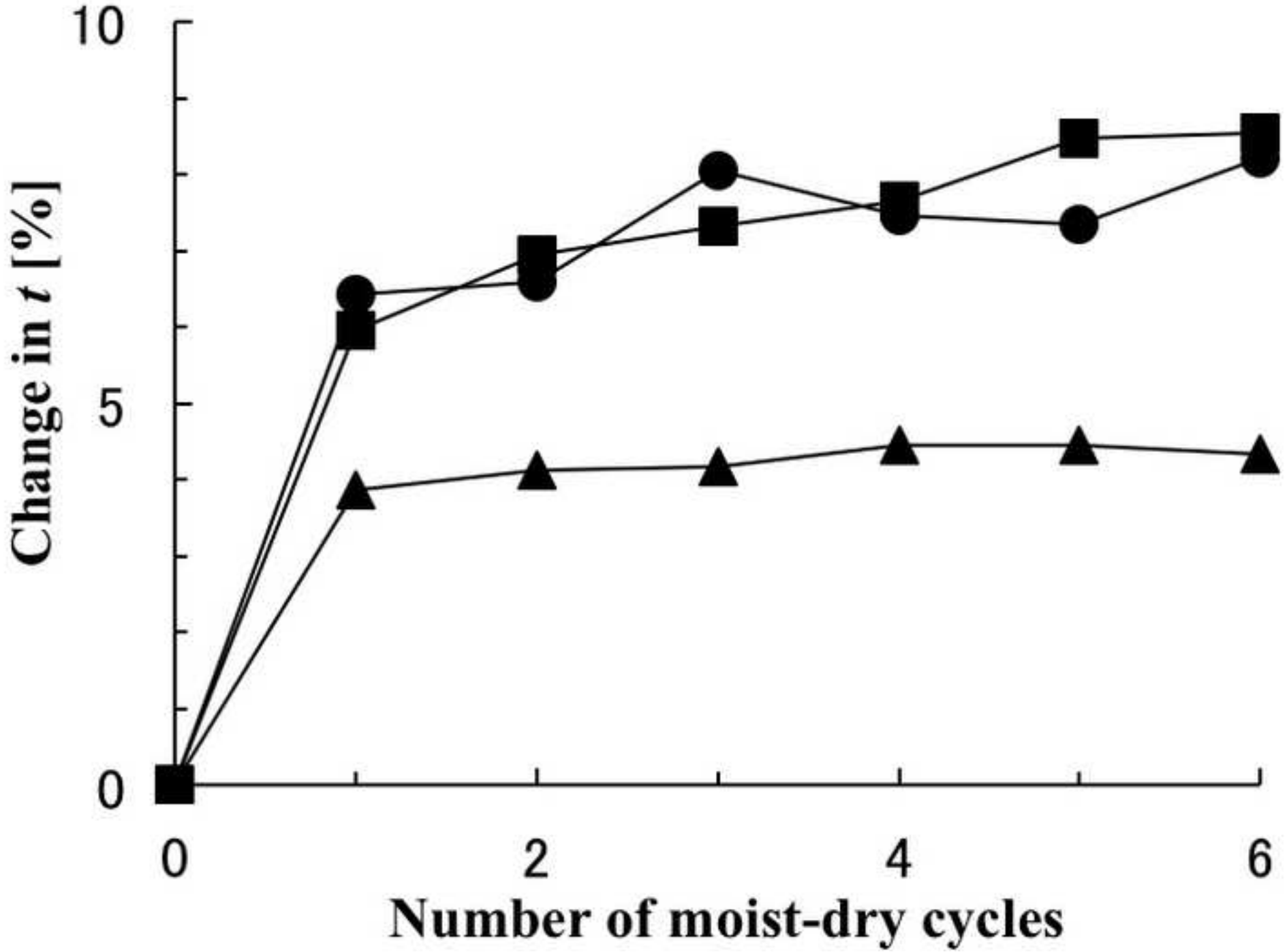

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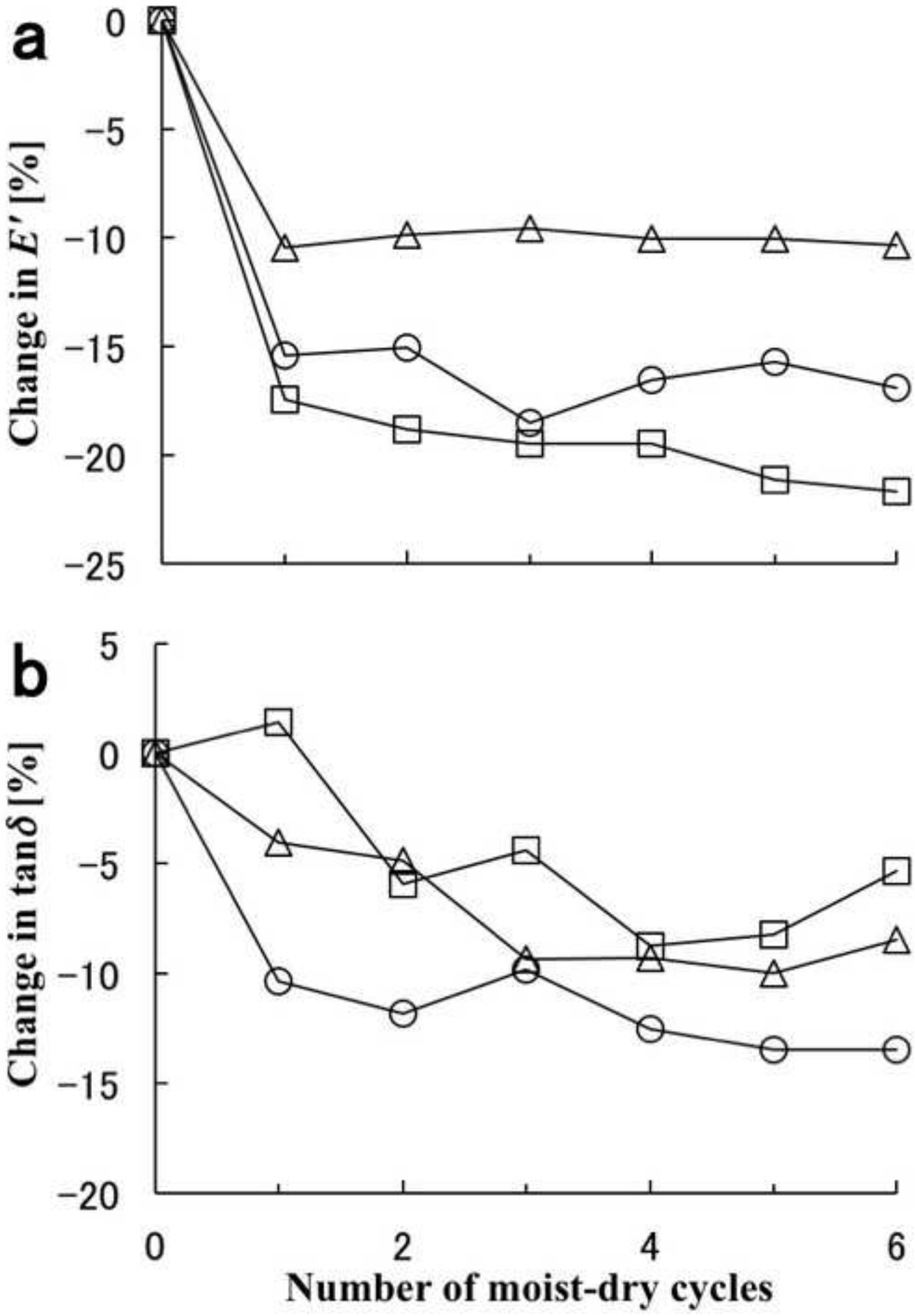

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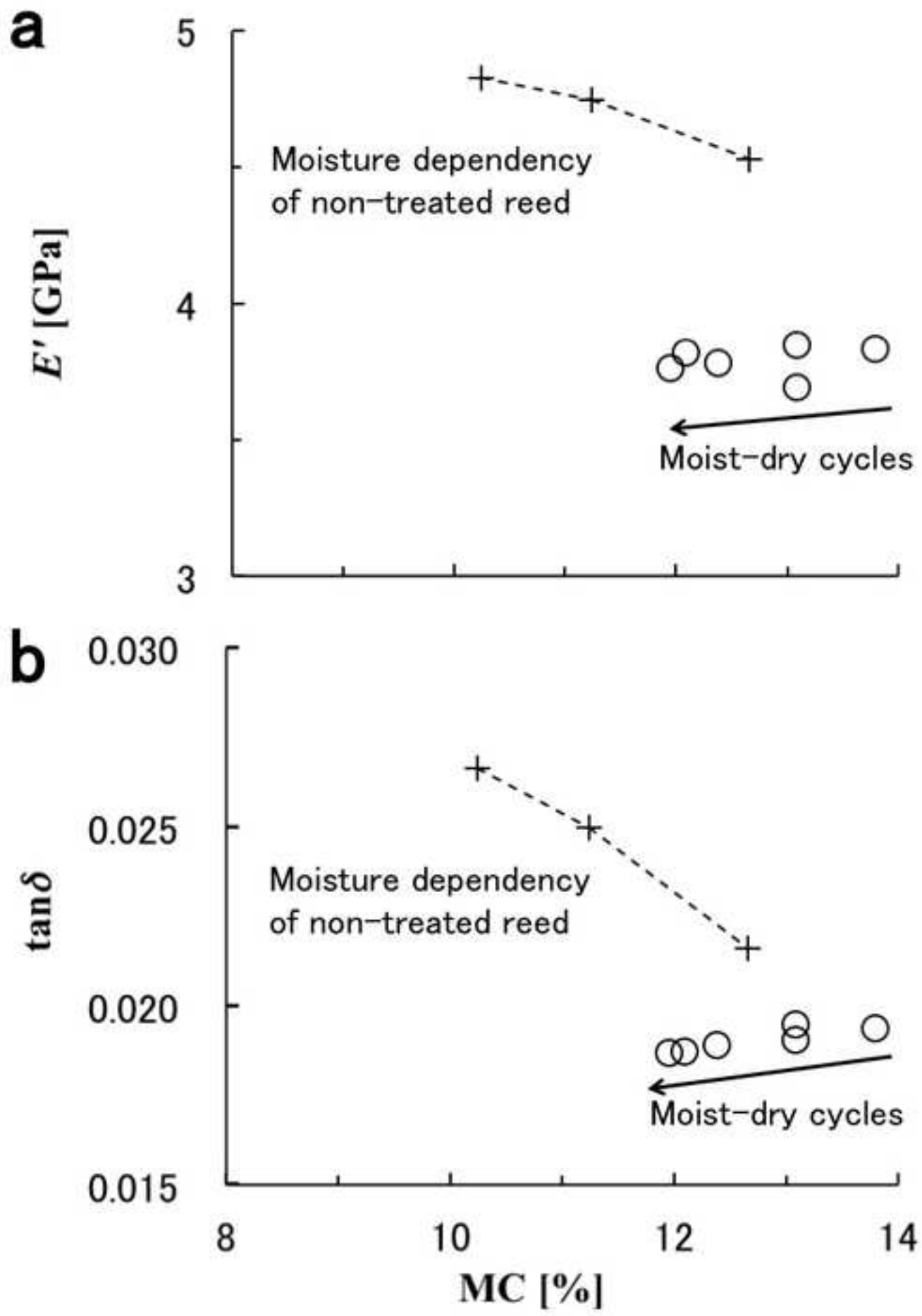

Dear reviewers,

We are grateful for your suggestive comments. Your comments were quite useful to improve our manuscript. We've revised our manuscript according to your suggestions, and some questions are answered in the following sheets. The revised phrases are red colored in the revised manuscript.

Comments from Reviewers #1 and our response

1) about the role played by extractives in determining wood MC. The part of extractive linked to the cell wall, establish a link with cell wall polymers that is in contrast with water molecules. It is normal knowledge that the higher the EC lower the EMC of wood. Your results show the opposite: the lower the content of Extractive the lower the EMC. Could you comment this point ?

- As described in our previous article (Obataya and Norimoto, 1995b), the reed shows extremely high EMC *at high RH* in the presence of extractives. On the contrary, the EMC is reduced by the extractives *at low RH*. Those opposites effects can be explained by the deliquescent nature of the extractives: the extractives adsorbs moisture only in highly humid condition. Thus the present results do not contradict to the previous article.

2) On page 6 lines 4 to 5 you speculate that extractives migrate from cell wall to the lumen, aggregate and reduce MC. How it would be possible? Do such re-aggregated extractives affect the water movement (and EMC) that occur within the cell wall matrix?

- Unfortunately we have no direct evidence such as microscopic observation, but similar phenomenon (changes in hygroscopicity due to the aggregation of sugar) is well known in the field of powder engineering as "moisture migration caking". That phenomenon is briefly mentioned in the revised manuscript.

3) Why the moist-dry cycles were carried out applying a fix time of vacuum at lower RH rather than to consider the constant weight as indicator of the new equilibrium? Could that be an explanation for the high MC (about 14%) shown by the non-treated samples of fig 8 at an RH 60%? All the EMC tables give for that RH value a maximum MC of 11%.

- Time span of moist-dry cycle was determined to be longer than the time required for the mass equilibrium of samples. This is added in the revised manuscript. The reason for higher MC (>14%) was considered to be due to the migration of extractives from the cell wall to the cell lumina. For the effects of extractives on the hygroscopicity of the reed, we've cited our previous article (Obataya and Norimoto, 1995b).

Thank you again for your useful comments.

Comments from Reviewers #2 and our response

General comments

This manuscript presents original experiments on the mechanical behaviour of reed, how it is affected by humidity cycling including loss of extractives and recovery of collapse, and some consideration on the importance for practical performance of reeds in woodwind instruments.
The topic is original and interesting from both fundamental and practical points of view, the experiments appear well conducted and reliable, and the article is generally clear, concise and illustrated by relevant figures. Therefore, the manuscript can be recommended for publication in Wood Science and Technology without hesitation, and with only very minor revision.

However, some few points could still be slightly improved, especially to provide the reader a better understanding of the conducted experimental plan and of some of the subsequent analyses. Namely, some more precisions could be given on the sampling/grouping of specimens, as well as on the time needed for stabilization of properties during cycles. In the discussion section, some equations or references might be inserted regarding the calculations of extractives content and shrinkage due to their departure. Another remark is the rather small number of references cited: 11 with only 5 "external" ones. However, as the authors' work on material properties of reed are probably the most complete on the topic this seems quite natural.
Once again, the manuscript is already of very good quality, and these reviewer comments could just help to improve understanding and/or precision of some points. Below, some detailed comments/suggestion are listed, following the sections of the manuscript.

Detailed comments

-Abstract:

Lines 13-14: there is a repetition of "by moist-dry cycles".

- Thank you for your correction. It was corrected.

-Introduction

In the 1st paragraph, it might be informative to cite some more recent works on musical/structural acoustics of reed, if available?

- Unfortunately we have no information about the reed, especially its acoustic properties. Please tell us if you have some information for that.

Line 16: "monosaccharides in parenchyma cells": is it clear if these compounds are located in the cell walls or in the lumen, or in which proportion? If known, a precision on this with reference would be informative for the following of the discussion.

- At least, the extractives *partly* locate in the cell wall as it has been proved that the thickness of parenchyma cell wall is reduced by the removal of extractives. However, it is technically difficult to distinguish the extractives in/out the cell wall.

-Materials and methods

*How were the 9 (wet-dry cycles) and 15 (moist-dry cycles) specimens selected out of the 108 original ones? Based on preliminary physical/vibrational tests? How was the grouping done? In the results and graphs, 3 groups of different densities are represented, this might be explained in this "material" section.

- The manuscript was revised according to your comments.

*Line 7 "absolute dry mass", line 13 "absolute dry weight", is the different use of mass/weight intentional, if yes why? Also, why was the absolute dry mass of samples for wet-dry and moist-dry cycles determined by different methods (P2O5 under vacuum versus 105°C)?

- The manuscript was revised according to your comments: the mass of absolutely dry sample is always described as “absolute dry mass” in the revised manuscript.
- For moist-dry cycle test, the absolute dry mass was determined only after the experiments, whereas in wet-dry cycle test, the sample was dried on P_2O_5 at room temperature to prevent any thermal degradation.

*line 13 "remove the water-soluble extractives" would be "remove the remaining water-soluble extractives", wouldn't it?

- The manuscript was revised according to your comments.

*For wet-dry cycles, specimens were dried at 65%RH, before vibrational tests, "until the equilibrium of mass". For moist-dry, "for 1 day". Is that sufficient for stabilisation of mass on the tested dimensions? Also, even when the mass is stabilized, are vibrational properties, notably damping, stabilised?

- The samples were equilibrated within a day, but it does not mean the equilibrium of vibrational properties. According to Hunt and Gril (J.Materials Sci.Lett. 1996, not cited in the present article), vibrational properties can continue to change by physical ageing effect, even when the mass is equilibrated. However, the present study aims to clarify the effects of short-time dry-moist cycle considering the actual situation in playing.

*Measurement of vibrational properties: although the description is rather clear, maybe giving a reference to the method could be useful. Also, the experimental incertitude on the measurements could be written (although, when looking at the quality of graphics, the incertitude of the method is expected to be small).

- We are sorry that we could not find any particular article describing the cantilever method, but it is a usual nondestructive testing. When the measurement is repeated 10 times, the variation in tanδ was about 0.8%. Thus the reliability and reproducibility of our method must be comparable to those of the other technique such as free-free flexural vibration method.

*Microscopic observations: the thickness of microtomed section could be given here. Also, were the same cross-sections observed before and after the different "treatments"? (i.e. the treatment was applied on the microtomed sections, not on the macroscopic samples?).

- We have not observed microtomed section, but observe the surface of solid (block) samples by using a stereo microscope.

-Results and discussion

*Throughout the results and figures, 3 trends for different densities are systematically presented. Is that always 3 individual specimens, or the average of several (3?) specimens (3x3 different densities = 9 specimens per type of cycling?). If it is the average, error bars could be included. If only 3 individual specimens are represented each time (out of the 9 or 6 depending on treatments), why? A note on this (maybe as soon as in the "material and methods" section) would also help to understand some portions of text such as "in the other specimens" or "in many cases", which otherwise appear a little bit vague.

- The 3 different trends indicate 3 individual specimens. Actually we've tested 9 samples but their behaviors are quantitatively different. To simply exhibit the common behavior of the reed, characteristic 3 samples were selected according to their density. The description is slightly modified considering the reviewer's question.

Effects of wet-dry cycles:

*The calculation of extractive content EC by means of correlation between m/me0 and EC is not straightforward to understand. On what sampling the correlation was established (how many specimens, untreated or after cycles)?.

- That is for the correlation recognized in the untreated specimens. The description was corrected to prevent misunderstanding.

*When introducing the calculation of shrinkage due to extractives' removal, it might be made more clear from the beginning of this sub-section that "(i)…, (ii)…, (iii)…" are hypotheses for a calculation. Some equation or reference to the calculation used might be informative here. Some explanation/reference on the assumed value of 1500 kg/m3 for extractives of reed would be useful. In addition, and this question is related to a comment above, the assumptions for this calculation imply that all extractives are located in the cell walls, which is not obvious especially in the case of

parenchyma cells. A reference or at least information on observations on this topic of cellular location of reed extractives would be helpful.

- Additional explanation was inserted in the revised manuscript. The reason for the assumption (1500 kg/m^3) is also explained.
- In bamboo, similar to the reed, extractives are not removed from green (fresh) sample even by mild boiling. Once it is dried, however, the extractives are ready to be removed by extraction in water (Suzuki 1953). This fact suggests that the extractives locate originally in the cell wall, whereas it becomes removable when the cell wall membranes are damaged by the first drying. That is a reason for our assumption that all extractives locate in the cell wall in the beginning.

*In the sub-section about the rigidity of reed plate, the definition/formula for bending rigidity could be given from the beginning (I: second moment of area is only made explicit lower in the sub-section). Although of general nature, this could be useful for the non-mechanician reader.

- Thank you for your suggestion. Additional explanation is given in the revised manuscript.

*page 6 lines 3-5: about the discussion on aggregation of deliquescent extractives in the lumen, that would reduce the MC: If these extractives are hygrophilic, they would still absorb moisture in the lumen, wouldn't they?

- It was technically difficult to directly observe the movement and aggregation of sugars, but the reduction in MC, especially at ambient RH condition, is attributable to the aggregation of sugar. Such a phenomenon is known as “caking” in powder engineering. Brief explanation is given in the manuscript.

[…] Practical performance of woodwind reeds:

*One or two references from musical acoustics, maybe more recent than the one cited (French 1971) might be interesting, if some are relevant to the studied topic? For a publication in Wood Science and Technology, however, this is not a priority and can be left to the authors' analysis of such literature.

- Thank you for your information, but we hope to focus on the role of extractives in the reed properties, rather than the acoustics of reed instruments.

*Conclusion of the sub-section, p7 lines 4-5: "the players should avoid prolonged playing to minimize the changes in performance". As the biggest magnitude of reported changes occur during the 1st one or two cycles, this would mean that players change their reed for virtually each performance, whereas the relative magnitude of changes appear to be smaller for subsequent cycles? This point could be made a bit less definitive, or alternatively explained a bit more.

- As suggested by the reviewer, the description was not clear. It is slightly modified in the revised manuscript to prevent any misunderstanding.

-References

As commented above, the number of cited references is not very big (11), although there is indeed not much literature on the material properties of reed. However, maybe some recent references in musical acoustics might be informative (not sure, this is just a question).

Also, there is a paper about the effect of humidity cycles on reduction of hygroscopicity in wood (Garcia Esteban et al 2005 Annals of Forest Science), would this reference be of some relevance to the presented results?

Finally, some of the comments made for the "materials and methods" section might call for references (see comments above), maybe from pevious work by the authors themselves. Specially, some reference about the time needed for stabilisation of vibrational properties, and about the cellular location of reed extractives, might be useful.

- We are very sorry that we could not find any (reliable) information about the relationships between the practical performance and material properties of reed. Especially the role of extractives has not studied yet.
- We have considered the effects of moist-dry cycling, reported by Esteban et al, but their results suggest that the MC at around 60%RH remains unchanged by the moist-dry cycling, whereas the MC at high RH is significantly reduced. Such a “seasoning effect”, probably due to the macromolecular conformational changes in wood polymers, should be distinguished from the present case involving the movement and loss of extractives.
- As mentioned above, the location of extractives is still unclarified, and as far as we searched, there is no literature to answer that question.

Again, thank you very much for your useful comments.