https://doi.org/10.31298/sl.148.3-4.4

INFLUENCE OF DESICCATION SENSITIVITY AND CRITICAL MOISTURE CONTENT ON *Quercus cerris, Quercus petraea* AND *Quercus robur* ACORNS

UTJECAJ OSJETLJIVOSTI NA ISUŠIVANJE I KRITIČNOG SADRŽAJA VLAGE NA ŽIREVE VRSTA *Quercus cerris, Quercus petraea* I *Quercus robur*

Cansu ÖZTÜRK[1]*, Servet CALISKAN[2]

SUMMARY

In this study, critical moisture contents and desiccation sensitivity of *Quercus cerris* (Turkey oak), *Quercus petraea* (sessile oak), *Quercus robur* (pedunculate oak) seeds were determined to see how desiccation affects acorn moisture content and germination behaviour. The moisture content of the harvested acorns was found to be 41% for *Q. cerris*, 46% for Q. *petrae*a and 45% for *Q. robur*. The acorns were separated into sublots, sprayed with distilled water to reach their maximum moisture content and then left to dry for 18 days. There were statistically significant differences in germination as a function of desiccation time and decreasing moisture content. Initial germinations were delayed. The highest moisture contents were 48% for *Q. cerris*, 51% for *Q. petraea* and 49% for *Q. robur* acorns. The highest water uptake was 17% in *Q. cerris*, 11% in *Q. petraea* and the lowest was 9% in *Q. robur*. The moisture content with a germination percentage below 50% was considered as the critical moisture content. In a period of 12-15 days after the beginning of the drying process, the acorns reached the critical moisture content. The germination percentage decreased from 83% to 43% for *Q. cerris*, from 100% to 44% for *Q. petraea* and from 97% to 43% for *Q. robur* as the moisture content decreased from the maximum to the critical moisture content. For *Q. cerris, Q. petraea* and *Q. robur*, the critical moisture contents at which acorns begin to lose viability were between 28-31%, 31-36% and 32-37%, respectively. The results of the present study provide guidance for nursery practices carried out on oak species, from acorn harvesting to seeding and post-seeding care.

KEY WORDS: germination, oak, pedunculate oak, sessile oak, Turkey oak, seed, recalcitrant seed

INTRODUCTION
UVOD

Oak is one of the most common broadleaf forest trees in the northern hemisphere, represented by about 500 species worldwide (Bonner and Vazzo, 1987; Pang et al. 2019; Wang et al. 2022). In Türkiye, it is represented by 17 species (23 taxa in total) (Yılmaz, 2014). The General Directorate of Forestry's 2022 statistics reveal that oak is present on 6.8 million hectares of land, with 41% of high forest and 59% of coppice forest (OGM, 2023). In recent years, with the demand for increasing forest areas in oak species, the use of acorn material has also increased. Acorns cannot survive on the ground for long due to their recalcitrant seed characteristics. Even if buried under the soil surface by factors

[1] Cansu Öztürk, İstanbul University-Cerrahpaşa, Institute of Graduate Studies, Avcılar, 34325 İstanbul, Türkiye
[2] Prof. Dr. Servet Caliskan, İstanbul University-Cerrahpaşa, Faculty of Forestry, Department of Silviculture, 34473, İstanbul, Türkiye
*Corresponding author: Cansu Öztürk, cansu.ozturk1@ogr.iuc.edu.tr, cozturk@sinop.edu.tr

such as climatic conditions, wild animals, or people, they are still exposed to desiccation conditions during shedding (Tweddle et al. 2003). Species with high carbohydrate nutrient reserves, such as oak, lose moisture quickly (Bonner, 1996). Therefore, it is recommended to harvest acorns as soon as they physiologically mature (Bonner and Vazzo, 1987). Acorns are generally recalcitrant seeds and lose their ability to germinate when they lose moisture (Bonner and Vozzo 1987; Bonner 1996). Recalcitrant seeds are a short-lived class of seeds that should not fall below a certain moisture content and have a high moisture content when they mature or shed (Berjak et al. 1989; Suszka et al. 1996; Bonner, 2008; Boydak and Çalışkan, 2021). When the acorns are mature, white oaks contain ~50% moisture and red oaks contain ~40% moisture (Bonner and Vazzo, 1987). However, viability is lost when the moisture of the acorns decreases below 25-40%, depending on the species (Boydak and Çalışkan, 2021). The moisture content of acorns can vary depending on seasonal precipitation, evapotranspiration, and climatic conditions over the years (Tweddle et al. 2003). Seed desiccation damage is the main cause of this loss of viability (Finch-Savage, 1992). Loss of viability in recalcitrant seeds is a direct result of seed desiccation damage (Finch-Savage, 1992), and the sensitivity of these seeds to desiccation is so great that they can suffer fatal damage even at 5% moisture loss (Connor and Sowa, 2003; Bonner, 2008; Xia et al. 2012; Bewley et al. 2012). When the seeds begin to dry out, their viability somewhat decreases at first due to the decrease in moisture content, but then the viability significantly decreases at a certain moisture content. This is called "critical moisture content" or "lowest safe moisture content" (Fing-Savage, 1992; Hong et al. 1996). Viability is lost as desiccation time increases.

The study has three main objectives. Firstly, to determine the changes in moisture loss over time. Secondly, to investigate the effect of moisture loss due to desiccation on germination behaviour. And thirdly, to identify the highest moisture content and critical moisture content of acorns of *Q. cerris*, *Q. petraea* and *Q. robur*.

MATERIAL AND METHODS
MATERIJALI I METODE

Study sites and acorn collections – *Područje istraživanja i prikupljanja žira*

Acorns were collected in October 2022 from natural distribution of *Q. cerris*, *Q. petraea*, and *Q. robur* in the Sinop province. The collection sites were Sinop-Central (41⁰ 57' 21" N, 34⁰ 48' 26" E; Karacaköy, 45 m a.s.l.) for *Q. cerris*, Sinop-Ayancık (41⁰ 56' 41" N, 34⁰ 44' 14" E; Ağaçlı village, 65 m a.s.l.) for *Q. petraea*, and Sinop-Central (41⁰ 57' 58" N, 35⁰ 05' 12" E; Çiftlik village, 30 m a.s.l.) for *Q. robur*. Acorns were collected from 10 mature trees of each of oak species, with a minimum distance of 50 m between them. Approximately 1500 acorns were collected from each oak species.

The collection sites exhibit the characteristics of the Black Sea climate in coastal areas and the continental climate in the inner regions. Based on climate data from the Turkish General Directorate of Meteorology between 1992 and 2022, the annual average precipitation is 735 mm and the annual average temperature is 14.8°C. Erinç (1965) defines precipitation efficiency as the ratio of annual average precipitation and annual average maximum temperature. According to Erinç (1965), Sinop has a precipitation efficiency index of 29.5, indicating a semi-humid climate.

Acorns were transferred to Sinop University Ayancık Vocational School Forestry Laboratory for measurement and laboratory testing. Acorns with abnormal discolouration and insect damage were removed. Only healthy acorns were used and identified through a flotation test (Bonner, 2003). For each species, 1500 seeds were stored in sealed polyethylene bags in a refrigerator at +2°C until the tests were carried out.

Acorn morphological measurements and initial moisture content – *Morfološka analiza žira i početni sadržaj vlage*

Acorn length and width were measured using digital calipers (aogo) on 100 randomly selected acorns from each species. The weight of 1000 acorns was determined, and the moisture content was measured using 25 acorns (5 replicates of 5 acorns) for each species. The fresh weight (FW) of the acorns was recorded on a precision scale, and after they were dried in an oven at 105±2 °C for 18 hours, their dry weight was measured and moisture determinations were made (Bonner, 2008).

Desiccation treatments – *Tretmani isušivanja*

The highest and the lowest moisture content of the acorns were determined in two stages. The acorns were divided into sub-seed lots of 30 acorns in polyethylene bags. The highest moisture content of the seedlots was determined using precision scales, and the acorns were then stored in sealed bags in a refrigerator at +2°C. The acorns' outer surface was sprayed repeatedly with distilled water until it was completely wet (about 10-15 ml per treatment). The weight of acorns was measured daily, and the process of spraying distilled water was repeated according to the established procedures (Finch-Savage, 1992; Suszka et al. 1996, Yılmaz, 2005). The bags were renewed once a week to prevent the spoilage of acorns by pathogens. The final moisture content of the acorns was determined when their weight remained constant, and the highest moisture content was found.

The second step was to determine critical moisture content. The acorns that reached the highest moisture content were left to desiccate at 30-35% relative humidity and at 15-18°C for 18 days. The weight of the acorns in each seedlot was then measured to determine the rate of acorn moisture loss as a function of time on the control day (D1), the 3rd day (D3), the 6th day (D6), the 9th day (D9), the 12th day (D12), the 15th day (D15) and the 18th day (D18) (Bonner, 1996; Ganatsas et al., 2017). Before performing the germination test on the acorn lots, they were dried in an oven at 105±2 °C for 16-18 hours and their moisture was determined. In the present study, the approximate moisture content reached with the germination percentage falling below 50% was determined as the critical moisture content (Bonner, 1996). The new moisture contents depending on the weight change of the sub-seed lots with known weight and moisture values were calculated according to the formulas below (Suszka et al. 1996).

$$FW2 = FW1X\frac{100-MC1}{100-MC2}$$

$$MC2 = 100 - \frac{FW1X(100-MC1)}{FW2}$$

MC1: initial moisture content (%), MC2: new moisture content (%), FW1: initial weight (gr), FW2: new weight (gr)

Germination tests – Ispitivanja *klijavosti*

Each germination test included 100 acorns of *Q. cerris*, *Q. petraea* and *Q. robur* (4 replicates x 25 acorns). Sterilized river sand in approximately 2 l plastic containers was used as a germination medium. Germination tests were carried out at a constant temperature of 20°C in the dark in a germination cabinet (NBİOTECH, NB-2050Q). The germinations were checked and recorded at regular intervals (Suszka et al. 1996). Acorns that had at least 5 mm radicles and showed geotropism were considered germinated (Caliskan, 2014). The germination tests were terminated after 28 days. The germination percentage and mean germination time (MGT) for each treatment were determined using the formula below (Bewley and Black, 1994).

$$MGT = \sum (t \times n) / \sum n$$

MGT: mean germination time (day), t: number of days since the test started, n: number of acorns germinated that day

Statistical Analysis – *Statistička analiza*

The effects of changes in acorn moisture on germination percentage and mean germination time were determined using an ANOVA test. ANOVA for germination characteristics is based on the following model: Y_{lk}=μ +M_l+e_{lk}, where Y_{lk} is the observed value. μ is the overall mean, M_l is the moisture content effect and e_{lk} is the error. Duncan's post hoc test was applied to determine statistically significant differences in germination characteristics (α=0.05). Acorn moisture loss due to desiccation time was evaluated by linear regression analysis. SPSS 2021 software was used for statistical analysis.

RESULTS
REZULTATI

The average length, width, weight of 1000 acorns and moisture content of the acorns are given in Table 1. The highest moisture contents found amounted to 48.3% in *Q. cerris*, 51.1% in *Q. petraea* and 49.2% in *Q. robur* on D1 (Figure 1). The maximum moisture content was reached in 11 days for *Q. cerris*, 8 days for *Q. petraea*, and 10 days for *Q. robur*. Moisture levels in *Q. cerris*, *Q. petraea*, and *Q. robur* show a linear decrease after 18 days of desiccation. Acorns that were left to desiccate at their maximum moisture content reached their harvested moisture content after 3 to 6 days for *Q. cerris*, and after 1 to 3 days for *Q. petraea* and *Q. robur* (Figure 1). The effects of changes in the moisture contents of acorns in *Q. cerris, Q. petraea* and *Q. robur* on the germination percentage and mean germination time are given in Table 2.

There were significant differences found in the desiccation treatments between the oak species in terms of GP and MGT. Decreases in germination percentages due to moisture loss in *Q. cerris*, *Q. petraea* and *Q. robur* are given in Figure 2. The effects of moisture content loss on MGT showed a similar pattern to the relationship between moisture content on germination percentage. The MGT increased as the moisture content decreased (Figure 3, Table 3).

Desiccation time had a notable impact on both the onset of germination and the overall germination percent-

Table 1. Morphometric characteristics of Quercus cerris, Quercus petraea, and Quercus robur acorns
Slika 1: Morfometrijske karakteristike žira vrsta Quercus cerris, Quercus petraea i Quercus robur

Species	Acorn width (cm)		Acorn length (cm)		Weight of 1000 acorn (gr)	Moisture content* (%)
	Mean±Se	Range	Mean±Se	Range		
Q. cerris	2.95±0.04	1.9-3.7	1.64±0.02	1.1-2.4	6200	41
Q. petreae	2.84±0.05	1.9-3.8	1.4±0.02	1-1.9	4400	46
Q. robur	3.61±0.06	2.3-4.7	1.72±0.02	1.2-2.1	7100	45

*Moisture content of acorns when harvested. ± indicates the standard error.

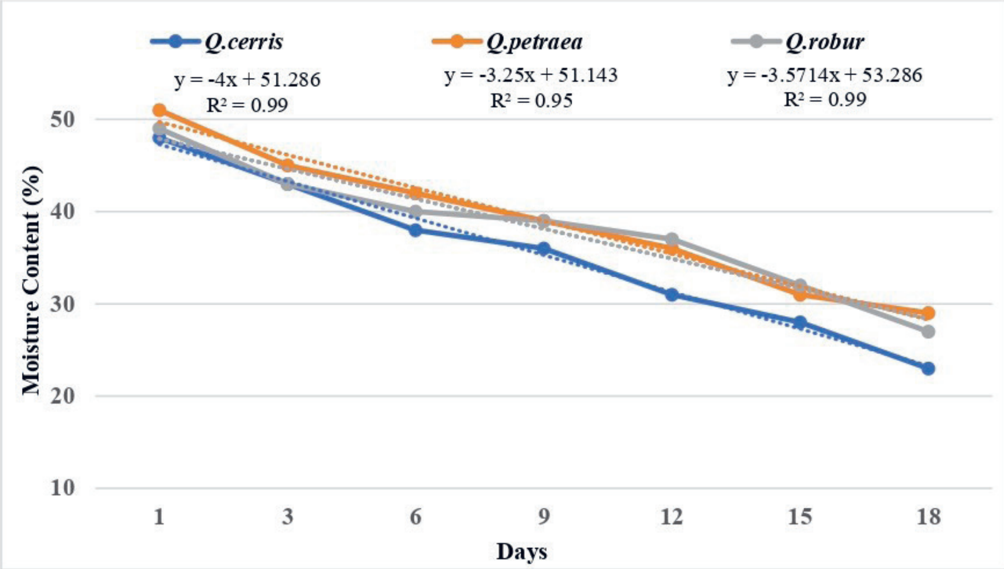

Figure 1: Acorn moisture content loss of oak species (*Q. cerris*, *Q. petraea*, *Q. robur*) at 15-18°C during 18 days of desiccation treatment
Slika 1: Gubitak vlage žira tri vrste hrasta (*Q. cerris*, *Q. petraea*, *Q. robur*) na 15-18 °C tokom 18 dana tretmana isušivanja

Table 2. ANOVA results regarding the effect of moisture content loss in *Q. cerris, Q. petraea,* and *Q. robur* acorns on germination percentage (GP) and mean germination time (MGT)
Tablica 2. Rezultati ANOVA testa koji prikazuju učinak gubitka sadržaja vlage žira *Q. cerris*, *Q. petraea* i *Q. robur* na postotak klijavosti i srednje vrijeme klijanja

		Q. cerris			*Q. petraea*			*Q. robur*		
	df	MS	F	p-value	MS	F	p-value	MS	F	p-value
GP	6	0.1511	65.70	0.000	0.3553	444.1250	0.000	0.2005	66.8333	0.000
Error	21	0.0023			0.0008			0.0030		
MGT	6	42.6964	48.756	0.000	65.8807	38.3429	0.000	18.2490	8.0141	0.000
Error	21	0.8757			1.7182			2.2771		

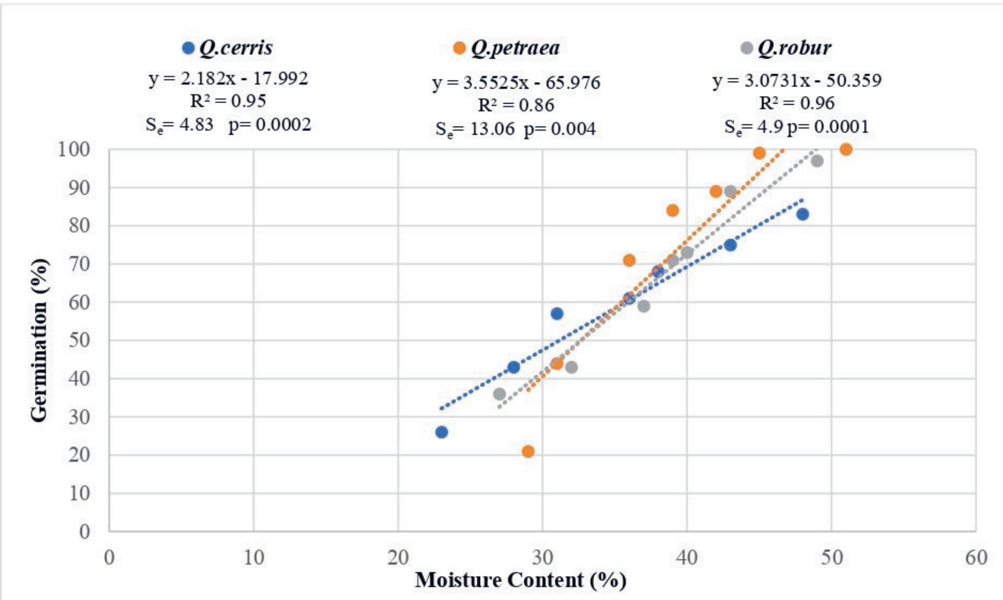

Figure 2. Effect of desiccation treatments on acorn germinations of *Q. cerris*, *Q. petraea*, and *Q. robur*
Slika 2. Učinak tretmana isušivanja na klijanje žira kod vrsta *Q. cerris*, *Q. petraea* i *Q. robur*

Table 3. The effect of acorn desiccation treatments on germination percentage and mean germination time in of *Q. cerris*, *Q. petraea*, and *Q. robur*
Tablica 3. Učinak tretmana isušivanja žira na postotak klijavosti i srednje vrijeme klijanja kod vrsta *Q. cerris*, *Q. petraea* i *Q. robur*

	Q. cerris			*Q. petraea*			*Q. robur*		
Day	MC (%)	GP (%)	MGT	MC (%)	GP (%)	MGT	MC (%)	GP (%)	MGT
D1	48.3	83±0.07f	13.2±0.88a	51.1	100±0.00f	8±0.83a	49.2	97±0.03d	13.2±1.73a
D3	42.9	75±0.05de	13.7±1.07a	44.7	99±0.02f	9.2±1.20a	43.3	89±0.05d	15.4±1.34b
D6	38.2	68±0.03cd	16.9±1.55b	41.6	89±0.02e	11.1±0.66ab	40	73±0.02c	16.5±2.47bc
D9	36.1	61±0.04c	19.6±0.69c	39.3	84±0.03d	11.8±1.35bc	38.9	71±0.04c	16.6±1.14bc
D12	31.4	57±0.04c	19.8±0.36c	35.5	71±0.05c	13.2±0.29cd	37.4	59±0.04b	17.2±0.59bc
D15	28.4	43±0.07b	20.8±0.91c	31.4	44±0.03b	18±2.14e	32.1	43±0.08a	18.2±1.16bc
D18	23.2	26±0.02a	20.9±0.60c	29.2	21±0.02a	18.4±1.73e	27.4	36±0.09a	20±1.43cd

The means in the same column followed by the same letters are not statistically different in Duncan's post hoc test ($P<0.05$); ± indicates the standard deviation.

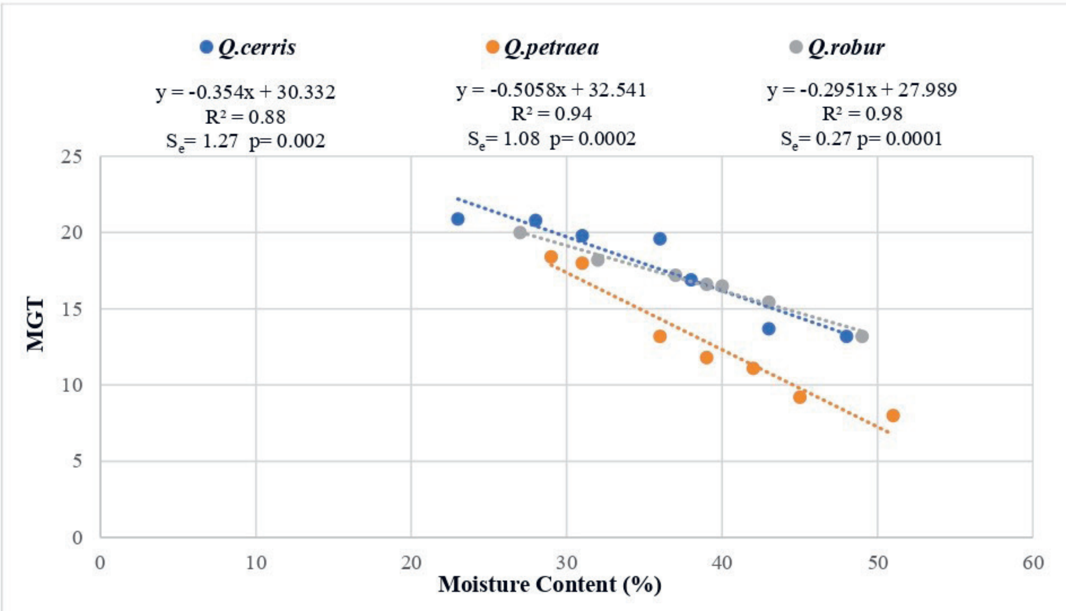

Figure 3. Effect of desiccation treatments on mean germination time of acorns of *Q. cerris*, *Q. petraea*, and *Q. robur*
Slika 3. Učinak tretmana isušivanja na srednje vrijeme klijanja žira kod vrsta *Q. cerris*, *Q. petraea* i *Q. robur*

age across all oak species, as shown in Figure 4. The initiation and completion of acorn germination shifted towards the final days of the germination test.

DISCUSSION
RASPRAVA

In terms of acorn size, *Q. robur* has larger acorns than *Q. cerris* and *Q. petraea*. There is a positive correlation between acorn size and 1000 seed weight (Bonner, 2003). In the present study, 1000 seed weights of *Q. robur* and *Q. cerris* were greater than that of *Q. petraea*. Ganatsas et al. (2017) found that large and heavy acorns had lower moisture loss. Devetaković et al. (2019) stated that germination in the group of large acorns was more than twice as high as in the group of smaller acorns. Additionally, nursery studies have reported that using large acorns has a positive effect on seedling quality (Roth et al. 2009; Roth et al. 2011).

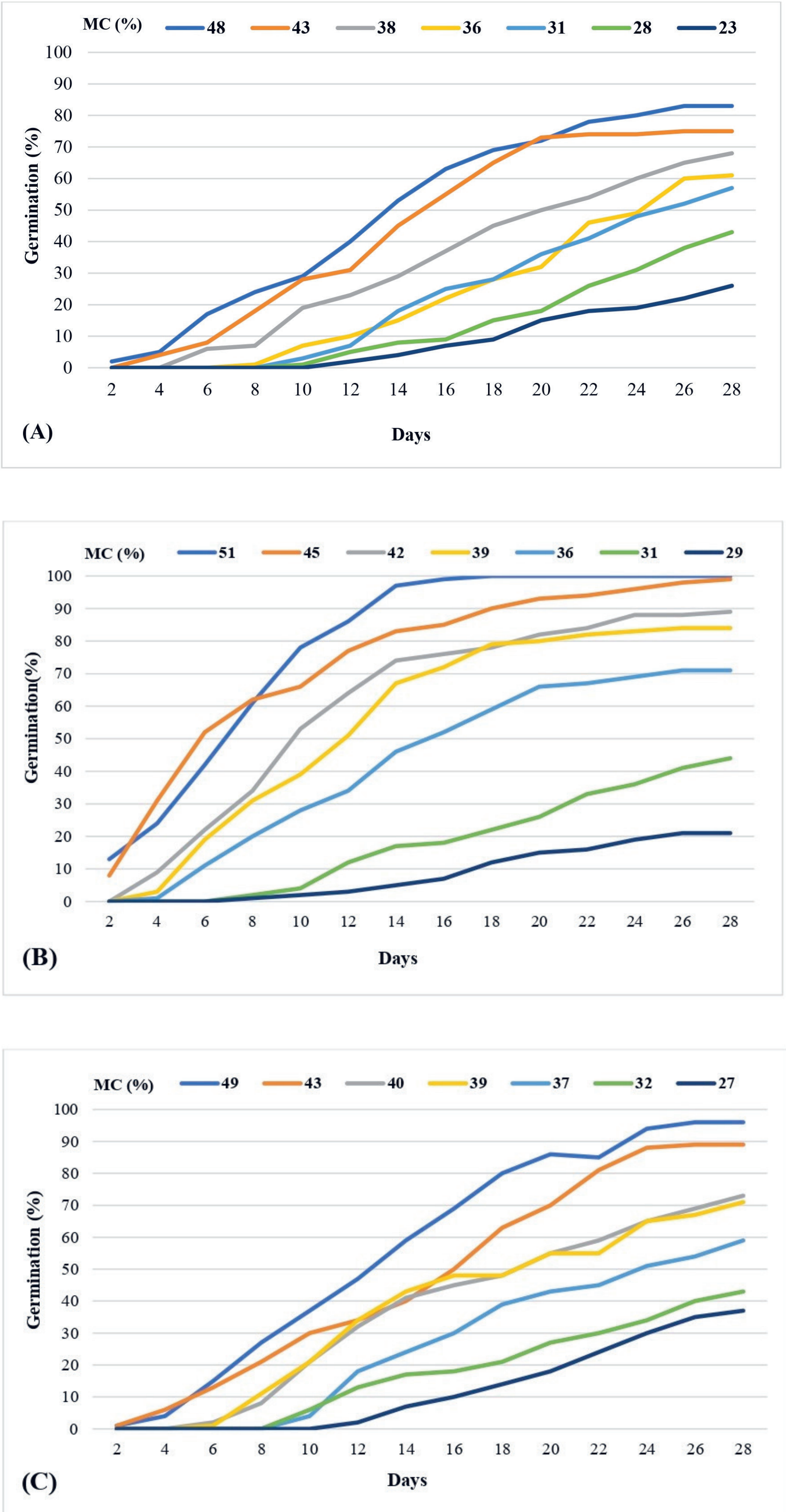

Figure 4. Acorn germinations of *Q. cerris* (A), *Q. petraea* (B), and *Q. robur* (C) as affected by desiccation treatments
Slika 4. Utjecaj tretmana isušivanja na klijanje žira kod vrsta *Q. cerris*, *Q. petraea* i *Q. robur*

In the present study, *Q. cerris*, *Q. petraea*, and *Q. robur* had an average moisture content of 41-46% at the time of harvesting. In some studies, the initial moisture content at the time of the collection was determined as 35% in *Q. petraea* (Tilki, 2010), 33-35% in *Q. ithaburensis* (Ganatsas et al. 2017), and 44% in *Q. ilex* (Leon-Lobos and Ellis, 2018), and it was found that there were different values between species. The highest moisture content (D1) had the highest germination percentage in *Q. cerris, Q. petraea,* and *Q. robur*. It was reported that the germination performance of *Q. robur* seeds increased in the first days after being saturated (Özbingöl and O'reilly, 2005). On the other hand, *Q. ithaburensis*, acorn moisture content increased by 5.7%-6.9% in 24 hours (Ganatsas et al. 2017). In the present study, the highest water imbibition was observed in *Q. cerris* (17%), and then *Q. petraea* (11%), while the lowest water uptake was observed in *Q. robur* (9%). It was stated that the difference in water imbibition rates among species is due to the characteristics of the pericarp (Xia et al. 2012; Ganatsas et al. 2017).

In the present study, the acorn moisture contents of *Q. cerris, Q. petraea,* and *Q. robur* followed a similar linear pattern by decreasing with desiccation according to the days. The study results confirm that acorn behaviour against moisture loss is similar in acorn studies conducted by Suszka et al. (1996), Xia et al. (2012), and Chmielarz et al. (2022). The moisture content of *Q. cerris*, *Q. petraea* and *Q. robur* decreased by about 50% (48%-57%-55%) at the end of 18 days. It was reported that the reason for the change in acorn desiccation rates between and within the species was not related to acorn oil content and acorn weight, but this change was mostly related to the acorn surface area, volume and coat properties (Ganatsas and Tsakaldimi, 2013; Ganatsas et al. 2017). *Q. petraea* rapidly lost moisture and had lower germination percentage than *Q. cerris* and *Q. robur.* The loss of viability due to desiccation and the variation in moisture content may vary depending on the year of collection, origin and species (Leon-Lobos and Ellis, 2018). Differences in the rate of moisture loss may be due to the high moisture content of the acorn at the time of shedding and the characteristics of acorn coats of the species (Suszka et al. 1996, Xia et al. 2012, Ganatsas and Tsakaldimi, 2013). The germination percentage significantly decreased with moisture loss in *Q. cerris*, *Q. petraea*, and *Q. robur* (Figure 2, Table 3). While there were linear gradual decreases in moisture contents during the first 6 days of desiccation, the content of moisture loss increased from the 9th day. After the 12th day, the effect of desiccation significantly affected the germination percentages. It has been statistically observed that germination percentage is highly dependent on moisture content. The decrease in moisture content is associated with the loss of viability in acorns. Bonner and Vazzo (1987) and Suszka et al. (1996) reported that germination is reduced by half when the moisture content is below 30% and there is a complete loss of viability when the moisture content is below 25%. Similar results were found for *Q. cerris*, *Q. petraea* and *Q. robur* in the present study. In addition, even when the moisture content was less than 30%, germination of the acorns was observed, albeit at a low germination rate. These results can be explained by the presence of acorns with a high moisture content still in the batch, as well as by the presence of acorns with different sensitivity and different tolerance to desiccation (Finch-Savage, 1992; Xia et al., 2012). In the present study, as the moisture content decreased, germination percentage decreased and the MGT increased (Table 3). In different studies, the effect of decrease in moisture on MGT is similar (Connor and Sowa, 2003; Özbingöl and O'reilly, 2005, Ganatsas and Tsakaldimi, 2013). After 15 days of desiccation, MGT increased from 4.4 days to 10 days in *Q. coccifera*, from 2 days to 7.6 days in *Q. pubescens* and from 4.4 days to 6.8 days in *Q. pedunculiflora*. However, *Q. pedunculiflora* was less affected by moisture loss than *Q. coccifera* and *Q. pubescens* (Ganatsas and Tsakaldimi, 2013).

The moisture content of *Q. cerris* in groups D3 and D6 was close to the moisture content at harvest time (41%). Rapid loss of acorn moisture after D15 showed statistically rapid decrease in germination percentages. According to Leon-Lobos and Ellis (2018), desiccation of the moisture content from 47.5% to 31% in *Q. cerris* reduced the germination percentage from 93% to 50%, therefore suggesting that the safest moisture content is approximately 40%. Despite the decrease in moisture content (51%-45%) in *Q. petraea* in D1 and D3 groups, no significant differences were observed in the germination percentage and MGT. The greatest effect on acorn moisture loss was observed when it dropped from D12 to D15. According to Suszka et al., (1996), *Q. petraea* acorns had 50% or more moisture content at the time of shedding, and the critical moisture content was 40-42%. In *Q. robur*, there was no significant difference between moisture loss and germination percentages in D1 and D3 groups, but there was a significant difference between moisture loss and MGT. It can be stated that the effect of moisture loss after D12 was high. In the present study, *Q. robur* was at 27% moisture content in D18, the germination percentage was 36%, while according to Suszka et al. (1996), the germination percentage was 14% at the same moisture content. Besides, Suszka et al. (1996) suggested that the moisture content of *Q. robur* acorns should not fall below 40%. Finch-Savage (1992) reported that the viability of *Q. robur* acorns was completely lost at 19% moisture content, and Xia et al. (2012) reported that it could tolerate desiccation up to approximately 20% moisture content.

On the other hand, in the case of different oak species, Bonner (1996) stated that the critical moisture content of *Q. nigra* was 10-12%, while Tilki and Alptekin (2006) stated that the critical moisture content of *Q. vulcanica* was 16%. Connor and Sowa (2003) stated that the acorn viability of *Q. alba* decreased significantly when the acorn moisture dropped below 30%. In *Q. fabri*, when the acorn moisture content decreased from 46% to 22%, the germination percentage decreased from 95% to zero, and when the moisture content was 32%, the germination percentage was more than 50% (Tian and Tang, 2010). Ganatsas and Tsakaldimi (2013) stated that the critical moisture content was 26% during the desiccation period of 5-7 days in *Q. coccifera* and *Q. pubescens*. They determined that the germination rate of *Q. ithaburensis* subsp. *macrolepis* was 100% when the moisture content was 35%, and at the end of 15 days of desiccation, 25% germination occurred at 15% moisture content, while the limit moisture at which germination percentages started to decrease was 25%. *Q. ithaburensis* subsp. *ithaburensis* was not affected by desiccation at room temperature for 15 days (GP 97%).

CONCLUSION
ZAKLJUCAK

The critical moisture contents for *Q. cerris*, *Q. petraea*, and *Q. robur* were in the ranges of 28-31%, 31-36%, and 32-37%, respectively. Germination percentage significantly dropped if the moisture content fell below the critical level. For *Q. cerris*, the germination percentage decreased from 83% to 43% as the critical moisture content decreased. For *Q. petraea*, the germination percentage decreased from 100% to 44%, and for *Q. robur*, it decreased from 97% to 43%. One limitation of this study is that it only includes one region for *Q. cerris*, *Q. petraea*, and *Q. robur* species. More detailed results can be obtained by conducting studies on different populations of these three species. The present study provides guidance for nursery studies on *Q. cerris*, *Q. petraea* and *Q. robur*, from acorn harvest to post-seeding care.

ACKNOWLEDGMENTS
ZAHVALA

The present manuscript was prepared on the basis of the PhD thesis conducted at İstanbul University-Cerrahpaşa, Graduate Education Institute, Forestry Engineering Doctorate Program by Cansu Öztürk under the supervision of Prof. Dr. Servet Çalişkan. We would like to thank Semra Alıusta and Jelena Batelić for their contributions. The authors would like to thank the anonymous reviewers and the editor for their valuable comments, which significantly improved the original manuscript.

REFERENCES
LITERATURA

- Berjak, P., Farrant, J. M., Pammenter, N. W. 1989: The basis of recalcitrant seed behaviour: cell biology of the homoiohydrous seed condition. Recent advances in the development and germination of seeds, Plenum Press, 89-108. New York.
- Bewley, J. D., Black, M. 1994: Seeds: Physiology of development and germination, Plenum Press, 445 p, New York.
- Bewley, J. D., Bradford, K., Hilhorst, H., Nonogaki, H. 2012: Seeds: physiology of development, germination and dormancy (Third Edition), Springer Science & Business Media, 703 p, New York
- Bonner, FT, Vozzo, JA 1987: Seed biology and technology of Quercus. General technical report SO-66. U. S. Department of Agriculture, Forest Service, 21 p., Southern Forest Experiment Station, New Orleans.
- Bonner, F.T. 1996: Responses to drying of recalcitrant seeds of *Quercus nigra* L. ANN. BOT-LONDON, *78*(2), 181-187.
- Bonner, F. T. 2003: Collection and care of acorns: a practical guide for seed collectors and nursery managers. Recuperado de http:// www. nsl. fs. fed. us.
- Bonner, F. T. 2008: The woody plant seed manual (No. 727). Forest Service, 1223 p.
- Boydak, M., Çalışkan, S., 2021: Ağaçlandırma, OGEM-VAK, ISBN: 978-605-70802-0-2, 728 p, Ankara.
- Caliskan, S. 2014: Germination and seedling growth of holm oak (*Quercus ilex* L.): effects of provenance, temperature, and radicle pruning. iForest, *7*(2), 103.
- Connor, K. F., Sowa, S. 2003: Effects of desiccation on the physiology and biochemistry of *Quercus alba* acorns. Tree Physiol., *23*(16), 1147-1152.
- Chmielarz, P., Suszka, J., Wawrzyniak, M. K. 2022: Desiccation does not increase frost resistance of pedunculate oak (*Quercus robur* L.) seeds. Ann. For. Sci, *79*(1), 1-12.
- Devetaković, J. R., Nonić, M., Prokić, B., Šijačić-Nikolić, M., Popović, V. 2019: Acorn size influence on the quality of pedunculate oak (*Quercus robur* L.) one-year old seedlings. Reforesta, (8), 17-24.
- Erinç, S. 1965: Yağış müessiriyeti üzerine bir deneme ve yeni bir indis. İstanbul Üniversitesi Coğrafya Enstitüsü Yayınları No:41, İstanbul.
- Finch-Savage, W. E. 1992: Embryo water status and survival in the recalcitrant species *Quercus robur* L: evidence for a critical moisture content. J. Exp. Bot., *43*(5), 663-669.
- Ganatsas, P., Tsakaldimi, M. 2013: A comparative study of desiccation responses of seeds of three drought-resistant Mediterranean oaks. For. Ecol. Manag., *305*, 189-194.
- Ganatsas, P., Tsakaldimi, M., Zarkadi, P., Stergiou, D. 2017: Intraspecific differences in the response to drying of *Quercus ithaburensis* acorns. Plant Biosyst. *151*(5), 878-886.
- Hong, T. D., Linington, S., Ellis, R. H. 1996: Seed storage behavior: a compendium, IPGRI, 104 p, Roma.
- Leon-Lobos, P., Ellis, R. 2018: Comparison of seed desiccation sensitivity amongst *Castanea sativa, Quercus ilex* and *Q. cerris*. Seed Sci. Technol., *46*, 233-237.
- OGM, 2023. Orman alanlarının ağaç türlerine göre dağılımı. Ormancılık İstatistikleri, 2022. https://www.ogm.gov.tr/tr/e-kutuphane/resmi-istatistikler, (Access Date: 27.09.2023).
- Özbingöl, N., O'reilly, C. 2005: Increasing acorn moisture content followed by freezing-storage enhances germination in pedunculate oak. Forestry, 78(1), 73-81.

- Pang, X., Liu, H., Wu, S., Yuan, Y., Li, H., Dong, J., Liu, Z., An, C., Su, Z., Li, B. 2019. Species identification of oaks (*Quercus* L., Fagaceae) from gene to genome. Int. J. Mol. Sci., *20*(23), 5940.
- SPSS. 2012: IBM SPSS statistics 21 core csystem user's guide, SPSS Inc., Chicago.
- Suszka, B., Muller, C., Bonnet-Masimbert, M. 1996: Seeds of forest broadleaves: from harvest to sowing. Editions Quae, 294 p, Paris.
- Tweddle, J.C., Dickie, J.B., Baskin, C.C., Baskin, J.M., 2003: Ecological aspects of seed desiccation sensitivity. J. Ecol., 91, 294–304.
- Tian, M. H., Tang, A. J. 2010: Seed desiccation sensitivity of *Quercus fabri* and Castanopsis fissa (Fagaceae). Seed Sci Technol, *38*(1), 225-230.
- Tilki, F., Alptekin, C. U. 2006: Germination and seedling growth of *Quercus vulcanica*: effects of stratification, desiccation, radicle pruning, and season of sowing. New Forests, *32*, 243-251.
- Tilki, F. 2010: Influence of acorn size and storage duration on moisture content, germination and survival of *Quercus petraea* (Mattuschka), J. Environ. Bio., 31(3), 325-328.
- Yılmaz, M. 2005: Doğu Kayını (*Fagus orientalis* Lipsky.) Tohumlarının Fizyolojisi Üzerine Araştırmalar. Doktora Tezi, İstanbul Üniversitesi Fen Bilimleri Enstitüsü, (M.; 180 s.)
- Yılmaz, H. 2014. *Quercus* L. (Editör) Akkemik, Ü., 2014: Türkiye'nin Doğal-Egzotik Ağaç ve Çalıları I, Orman Genel Müdürlüğü Yayınları, 678-702 s, Ankara.
- Xia, K., Daws, M. I., Hay, F. R., Chen, W. Y., Zhou, Z. K., Pritchard, H. W. 2012: A comparative study of desiccation responses of seeds of Asian Evergreen Oaks, *Quercus* subgenus Cyclobalanopsis and *Quercus* subgenus *Quercus*. S. AFR. J. BOT, *78*, 47-54.
- Wang, Y., Xu, C., Wang, Q., Jiang, Y., & Qin, L. 2022. Germplasm resources of oaks (*Quercus* L.) in China: utilization and prospects. Biology, *12*(1), 76.

SAŽETAK

U ovome radu određeni su kritični sadržaj vlage i osjetljivost na isušivanje sjemena vrsta *Quercus cerris* (hrast cer), *Quercus petraea* (hrast kitnjak) i *Quercus robur* (hrast lužnjak) kako bi se istražio utjecaj isušivanja na sadržaj vlage u žiru i na klijanje. Sadržaj vlage u ubranom žiru iznosio je 41 % za *Q. cerris*, 46 % za *Q. petraea* i 45 % za *Q. robur*. Žirovi su raspoređeni u podgrupe, poprskani destiliranom vodom kako bi se postigao maksimalan sadržaj vlage i zatim ostavljeni da se suše 18 dana. Dobivene su statistički značajne razlike u klijavosti u ovisnosti o vremenu isušivanja i smanjenju sadržaja vlage, a početak klijanja je odgođen. Najveći udio vlage u žiru iznosio je 48 % za *Q. cerris*, 51 % za *Q. petraea* i 49 % za *Q. robur*. Najveći unos vode iznosio je 17 % za *Q. cerris*, 11 % za *Q. petraea*, a najmanji 9 % za *Q. robur*. Sadržaj vlage s postotkom klijavosti ispod 50 % smatra se kritičnim sadržajem vlage. U razdoblju od 12 do 15 dana od početka procesa isušivanja žirovi su dosegli kritičnu vlagu. Postotak klijavosti smanjio se s 83 % na 43 % za *Q. cerris*, sa 100 % na 44 % za *Q. petraea* i s 97 % na 43 % za *Q. robur*, ovisno o tome kako se sadržaj vlage smanjio od maksimalnog do kritičnog sadržaja vlage. Za *Q. cerris*, *Q. petraea* i *Q. robur* kritični sadržaji vlage pri kojima žir počinje gubiti vijabilnost iznosili su 28-31 %, 31-36 %, odnosno 32-37 %. Rezultati ovog istraživanja pružit će smjernice za rasadničke prakse koje se primjenjuju na vrstama hrasta, od berbe žira do sječe i njege nakon sječe.

KLJUČNE RIJEČI: klijavost, hrast, hrast kitnjak, hrast lužnjak, hrast cer, sjeme, rekalcitrantno sjeme