Original Research Article

Influence of cone physical characteristics andextraction exposure period on seed yield of *Pinuspatula*

Abstract.

This study examines the correlation between extraction exposure periods and cone physical characteristics on *Pinuspatula* seed yield. Systematic random sampling was employed for tree identification in an even-agedclonal seed orchard, and the laboratory phase was laid down as a factorial experiment with two factors:cone physical characteristics and extraction exposure period at three levels. Seed counts were taken for cones categorized as; heavy,light, narrow, and wide at three extraction exposure periods6 hours, 12 hours, and 24 hoursin a constant oven temperature of 65°C.The experiment had 12 (L1,H1,N1,W1,L2,H2,N2,W2,L3,H3,N3,W3)treatments with 60 cones per treatment. The time spent counting and returning cones during the inter-stage observation ranged from 10 to 15 minutes.Data collected were tabulated and means analyzed using ANOVA with results generated as per the objectives. The number of seedsreleasedwithin the hours of exposure was captured as the seed extraction rate.The first six hours yielded the optimum number of seeds per conewith the mean highest number of seeds from wide cones. The lowest mean number of seeds released observed was 28, fromlight cones, while the highest mean number of seeds was observed to be 56 from wide cones. Cone sorting based on size before extraction is recommended for optimized seed yield. The stages of seedextraction employed here can be used in mechanized seed extraction cabinets equipped with timers at controlled temperatures.

Keywords:Pinuspatula, cone characteristics, extraction, seed yield

Introduction

Pines are one of the fast-growing exotic tree species established for commercial plantation development in East and Southern Africa (1,2).The bulk of seed extraction is concentrated in pine cones due to the high demand for pine seed(3–6).*Pinuspatula* is a serotinous pine and thus produces serotinous cones(7–9). Serotinous cones retain their seeds for one or more years following maturity (10–13) with seed release often occurring in response to an environmental stimulus such as high temperature (13,14).

Seeds extraction from cones of many species requires drying either natural or artificial heat sources and several methods have been employed for seed extraction from such cones (3,15–17).Challenges in seed extraction from cones have been attributed to scale opening and deflection which has been observed to be changing between coniferous species and also cone parts. The middle and top parts show significant deflection in some species while the next-to-stem part does not change its position significantly (3). *P. patula* is one of the species whose cone opening has demonstrated more reliance on cone width than cone length as there is little or no deflection on the next-to-stem(17).Silviculture focused on optimizing the seed extraction process is expected to enhance species seed production and preservation(18). The control of energy use in the process of seed extraction is important to ensure sustainable development while promoting the conservation of natural resources(19). The seed extraction process has been used in wet and humid pine-growingcountries for the controlled production of seed from silviculturalextraction facilities(20). Conifers have displayed between-species and within-species cone differences in terms of cone morphology, density, mass, weight, color, degrees of asymmetry, differences in scale tension, the effect of environment on bonding strength, and genetic differences in bonding agent(21,22).

The mechanism of scales opening in Pinus genera has also been proved to experience significant differences longitudinally (lengthwise), than cross-sectionally through shrinkage from wet to dry (23). Whereas cone length, diameter, and volume do not vary significantly by stand density, tree diameter, or crown position, cone dry weight differssignificantly between released and unreleased crop trees. The number of potentially productive scales per cone alsovaries significantly by location within the crown with greater numbers in the upper crown. Cone orientation, based on uprightness in *P. strobiformis* has also been reported to have no significant effects on seed extraction rates calculated as the number of seeds released per second but there existed cone opening differences over different times of the year (24). Information on cones and seeds has been found as effective guides for breeders when evaluating seed production from seed orchards (25).

A few pines have worked on examining the ideal conditions for seed release from serotinous cones and a variety of methodological approaches have been applied where these conditions have been examined. Typical approaches focus on the temperatures required to release the scales of serotinous cones and involve either heating cones in ovens or immersion in water(11,12,26). Previous studies have reported that pine cones open to release seed through a combination of temperature and humidity which varies widely in the pine-growingregions of the world (13,27,28). Another factor affecting pine cone opening is the presence of resin which occurs in many species (13). In these species, cone scales remain closed due to sealing with resin which requires high temperatures for resins to melt and cones to open.An increasein temperature which was comparable to longer exposure periods has been shown to affect seed release(29).

Artificial drying of cones in heated kilns has been recommended for cool moist climate species where the climate is not suited for air drying (5,30). In Kenya, cones are sun-dried in open-sided sheds covered with plastic roofs, where they open after 2 to 14 days. The duration of cone opening is long due to the low temperatures in pine seed extraction regions. *Pinuspatula* is a priority commercial tree species in Kenya, and therefore requires the availability of information on seed extraction efficiency. The study seeks to rove on the extraction practice by the use of empirical data to demonstratethe efficiency of artificial seed extraction technique that shortens the extraction period and optimize seed release.This will further enhance the planning processes for seed collection and production, especially for germplasm producers. The findings of this study will improve the existing knowledge and procedures of seed extraction from cones by providing new insights into the process.

The objectives of this study therefore were:

i)to assess the correlations of cone width and exposure period on seed release and ii) to assess the correlations of cone weight and exposure period on seed release

Materials and methods

*Stand description and tree selection:*A 2006 *Pinuspatula*clonal seed orchard stand was used as the source of trees and cones for this study. The seed source is situated in the Kamara block of Londiani forest, Kenya. The spacing used during establishment was 5m by 5m and the stand was pollarded in 2019. The stand has a mean height of 26.5m.Forty-five trees were systematically selected with a random start. The trees were marked and using a diameter tape, the diameter at 1.3 meters above ground, referred to as the diameter at breast height or DBHof each sampled tree was measured to examine whether the cone characteristics of each tree are correlated with tree size.Londiani area is cool and moist most of the year and is at an elevation of 2,308 m asl. The average temperatures during the time of this study ranged between 10.5°C and 25°C. The area has two rainy seasons, long rains occurring in the months of March to May with an average rainfall of 750 mm for the three months, and short rains in October to December with average rainfall for the three months of 423 mm. The driest months are January to February and August to September(31).

*Cone collection:*At the time of cone collection (June 2022), four of the selected trees had no mature cones while others had sufficient numbers thus the number of cones collectedper tree ranged from 11 to 63 making a total of 1980cones collected. Given that cone, maturity age has been found to influence opening temperature in some species, such as *P. halepensis*(11), observation of cone color (shiny brown to silver grey) was the criteria for mature cones of the current season.The cones were packed in gunny bags for delivery to the KEFRI Londianilaboratory situated at35.607270°E longitude and 0.155520°S latitude.

Once in the laboratory,measurementsof width and weight were taken by use ofan electronic caliper and a KERN &Sohn (KB 10000-1N) balance.The cones were categorized as either; narrow,wide, heavy, or light depending on the width and weight, whereby the ranges used were; 20g to 27g for light, 28g to 34g for heavy, 2.5cm to 2.8cm for narrow and 2.9cm to 3.2cm for wide cones respectively(32).These cones were thenexposed to artificial extraction conditions in ovens set at 65□(17). Observations ofthe seed released were done after 6 hours, 12 hours, and 24 hours.The categories under investigation were; Light cones, Heavy cones, Narrow cones, and Wide cones denoted as L, H, N, and W respectively with alphanumeric 1,2,3 representing extraction exposure periods; 6 hours, 12 hours, and 24 hours. Whereas exposure periods and cone characteristics were treatments, the variable was the seed released within the periods. The examined cases of seed extraction were compared in terms of cone weight and width, and the quantity of seed obtained at the extraction exposure times. The conventional way of seed drying in beds was the control from which daily observations were made for up to 21 days. A set of 30 cones from each of the categories (light, heavy, wide, and narrow) were set in Petri dishes and placed outside under the sun, and observed for seed release.

Descriptive statistics were applied to study the cone composition within each category. Thevariables and factors were subjected to a one-way analysis of variance (ANOVA) to determine the differences between and within groups. Tukey's HSD (Honestly Significant Difference) was used to find significant differences in means between groups at p=0.05.The correlations between the cone's physical attributes and the diameter of the tree were determined by the linear regression method to account for the documented relationships between tree size and cone traits (33–36).

Results& Discussion

Tree diameter and cone characteristics. The mean tree dbh was 34.6 ±1.21 cm with no significant differences in dbh among the sampled trees at p=2.44 (Fig. 1). Mean cone weightper tree rangedfrom9.3 to 42.4 g, giving an overall mean cone weight of28.5±1.20g and also showed no significant differences between cones from individual trees (p=2.43). The mean cone width per tree ranged from 2.1 to 3.4cmwith no significant differences (p=0.09).Correlation analysis of the three variables dbh, cone width, and cone weight resulted in a greater positive correlation between tree dbh and cone width (r=0.082825) than tree dbh and cone weight (r=0.005022). The correlation between cone weight and cone width had the strongest positive relationship r=0.796554.

Many studies have shown positive correlations between cone and pine seed production with its DBH and height used as predictors (10,37,38). Cone and seed production in other pines has also been shown to be positively influenced by larger basal areas(22,39). Other factors such as stand density, climatic variations, and the morphological parameters of trees also influence their reproductive capacity (40–42). It was reported that in some pines (for example Aleppo), sub-humid climate enhances cone production over semi-arid conditions. The environmental factors in all the sites of this study were the same and given the homogeneity of the stand, between-trees differences in cone abundance were minimal (43–45).

However, this is not always the case as previous studies on *P. sylvestris* and *P. koraiensis*, clonal seed orchards that were expected to express homogeneity in phenotypic traits, showed variations in cone and seed characters (46–48). These characters were as follows: cone length, cone width, cone weight, apophysis length, apophysis width, number of filled seeds, the total number of seeds, seed length, seed width, seed weights, opened carpel, and the total number of carpels(49,50). Seed production from seed orchards can be enhanced by improving cone traits such as cone abundance per tree, number of seeds per cone, and seed weight (43,51).

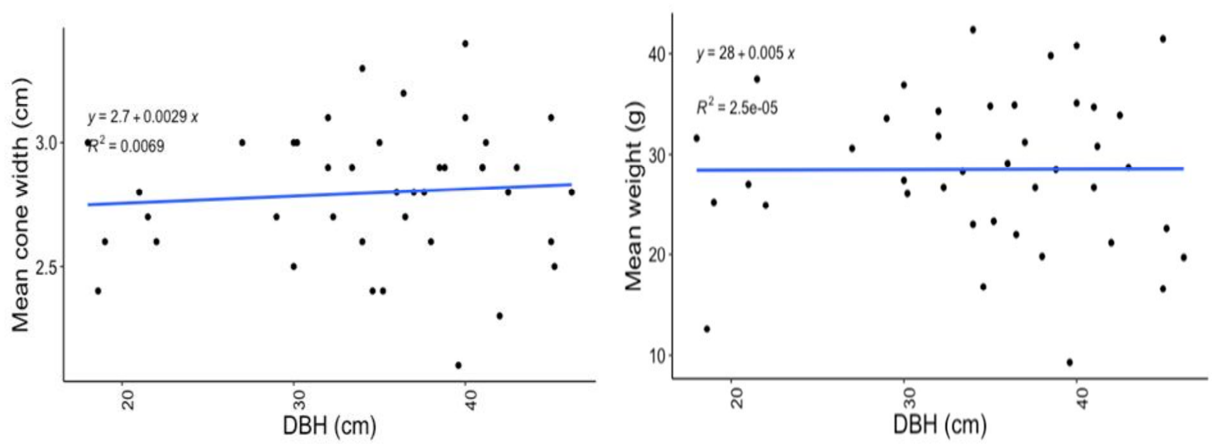

Figure 1:Correlation between tree dbh and cone characteristics

Cone Characteristics and Seedyield: For the groups within the first exposure treatment L1,H1,N1, and W1the number of seeds released per coneranged from 0-81, 0-128,1-103, and4-107 respectively.The seed yield reduced with progression in time with much of the seed released within the first hours (Fig. 2). Overall, there were significant differences (p=0.00) within the groups based on extraction period and cone physical characteristics.The current findings corroborate with previous work that, other factors notwithstanding, the size of cones is positively correlated with seed yield. The wide cones released more seeds (32,36,52).High temperatures cumulatively favor seeds released over time (13,53,54). Similarly, this study showed a positive effect on seed release cumulatively with an increase in exposure period regardless of the cone's physical characteristics. The extraction rate was highest within the first six hours and lowest for narrow cones at the end of 24 hours under controlled conditions.

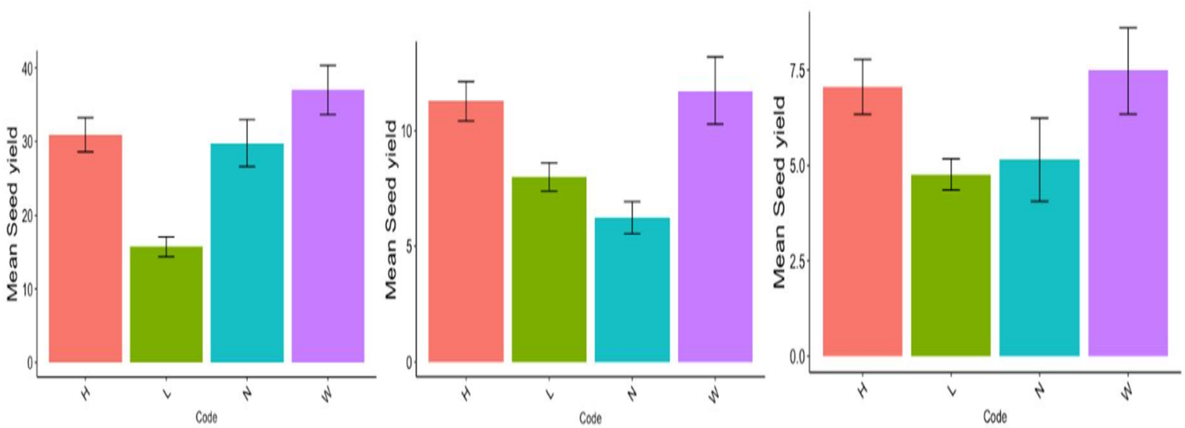

Figure 2:Mean seed yield at the end of extraction periods 1, 2 & 3 based on the cone characteristics heavy (H),light(L), narrow(N),and wide(W).

In all three phases of extraction, cone physical characteristics showed a significant influence on seed yield at p=0.05. In the first phase of extraction,significant differences in seed yield emerged between light and narrow cones, whereas heavy and wide cones showed no significant differencesthroughout the extraction periodat *p*=0.24.F test between groups revealed a significant difference in seed yield as a result of cone width as the other groups showed no statistical differences in seed yield.

Table 1: Variation in seed yield based on cone characteristics and phases of extraction

Treatment	L1	H1	N1	W1	L2	H2	N2	W2	L3	H3	N3	W3
Mean seed yield(x± se)	15.7±1.38	30.9±2.31	29.8±3.15	37.0±3.36	8.0±0.62	11.3±0.86	6.2±0.69	11.8±1.45	4.76±0.42	7.1±0.72	5.2±1.10	7.5±1.13
sd	15.49	27.58	25.59	26.05	6.96	10.28	5.61	11.25	4.66	8.61	8.93	8.74
ci	2.733	4.561	6.292	6.731	1.227	1.699	1.379	2.907	0.821	1.424	2.194	2.258
%seed yield	55	63	74	66	28	23	14	21	17	14	12	13
%cumulative seed yield	55	63	74	66	83	86	88	87	100	100	100	100
Performance-based on the extraction phase	64				22				14			

*L,H,N,W:cone characteristics light, heavy, narrow, wide andwide cones, 1,2,3: seed extraction exposure periods from 0 to the 6th hour, 6thhour to the 12thhour, and the 12th hour to the 24thhour, x: group mean, se: standard error, sd: standard deviation, ci:confidence interval

The mean cumulative number of seeds per cone from each of the categories was as follows: L=28, H=50, N=38, and W=56 (Fig.3) Optimum seed release was observed at the end of the first 6 hours with the highest yield from wide cones with 64% of the total seed released. Cone weight and cone width were found to be positively correlated with the number of seeds releasedwhereas an increase insize showed an increase in the number of seeds released.

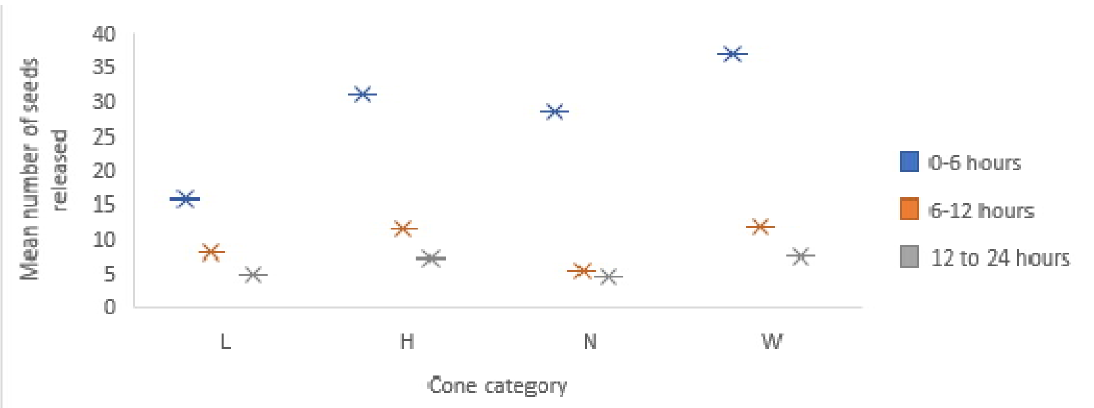

Figure 3: Seed release concerning extraction exposure periods and cone characteristics

The extraction rate was highest within the first six hours and with wide cones demonstrating the best performance yielding an average of six seeds per cone per hour (Fig.4). The extraction rate in all the groups dropped as the extraction period increased with the lowest observed in narrow cones 0.4 seeds per cone per hour between 12 and 24 hours.

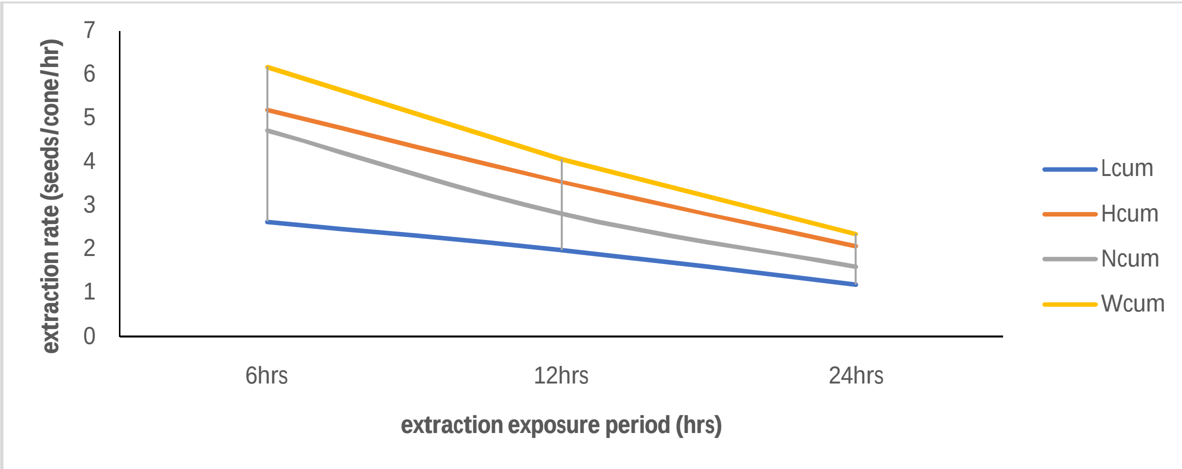

Figure 4: Extraction rates of seeds from Light (L), Heavy (H), Narrow (N), and Wide (W) cones

Combinations of cone physical traits showed that heavy and wide cones performed better in seed release both at 12 and 24 hours(Fig 5). The slowest cone opening was observed in natural sun-drying conditions while others did not open at all. This was attributed to fluctuating temperatures as some days were not so sunny.Many factors have been attributed to poor cone opening such as high moisture levels, due to early harvesting, fungal and insect damage as well as case hardening of cones during storage (33,37,39,46,55). In this study, most of the cones that did not open were the narrow ones subjected to natural sun-drying conditions for 21 days. These cones had signs of either physical damage or fungal attack. Delays in *P. patula* and *P. radiata* cones opening due to moisture levels had been ruled out in a previous study that showed temperature had a significantly greater influence on cone opening than moisture content (13,17).

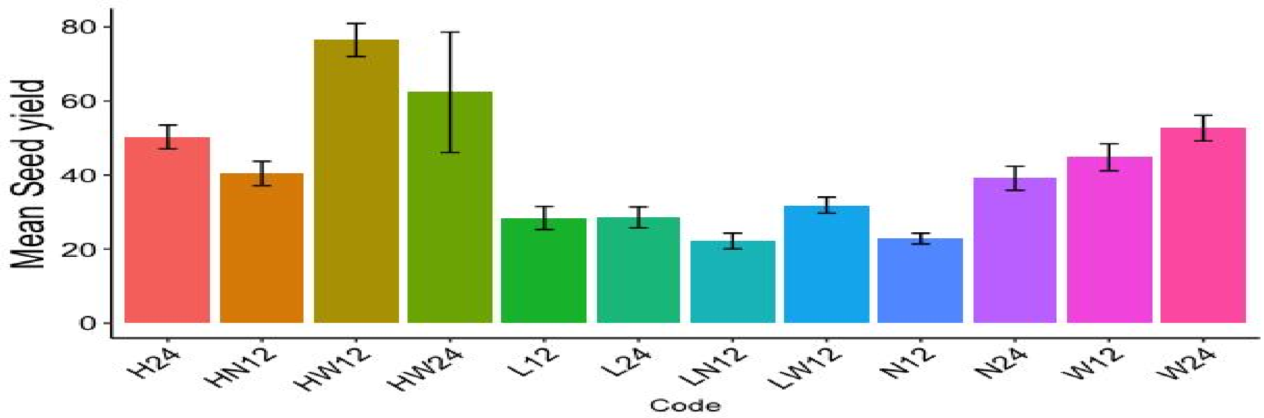

Figure 5:Comparison seed yield extracted under Combined factors;extraction exposure period and one or two of the cone characteristics where H24=heavy cones exposed to 24 hours of extraction, HN12=heavy yet narrow cones exposed to 12 hours of extraction, HW12=heavy and wide cones exposed to 12 hours of extraction, HW24=heavy and wide cones exposed to 24 hours of extraction, L12=light cones exposed to 12 hours of extraction, L24=light cones exposed to 24 hours of extraction, LN12=light and narrow cones exposed to 12 hours of extraction, LW12=light yet wide cones exposed to 12 hours of extraction, N12=narrow cones exposed to 12 hours of extraction, N24=narrow cones exposed to 24 hours of extraction, W12=wide cones exposed to 12 hours of extraction, and W24=wide cones exposed to 24 hours of extraction

Seed yield from cones exposed to natural seed extraction for up to 21 days in drying beds was observed to have significant differences based on cone characteristics (Fig 6, 7 & 8). Narrow and light cones showed no significant difference in mean cumulative seed at the end of the 21 days (p=0.67).

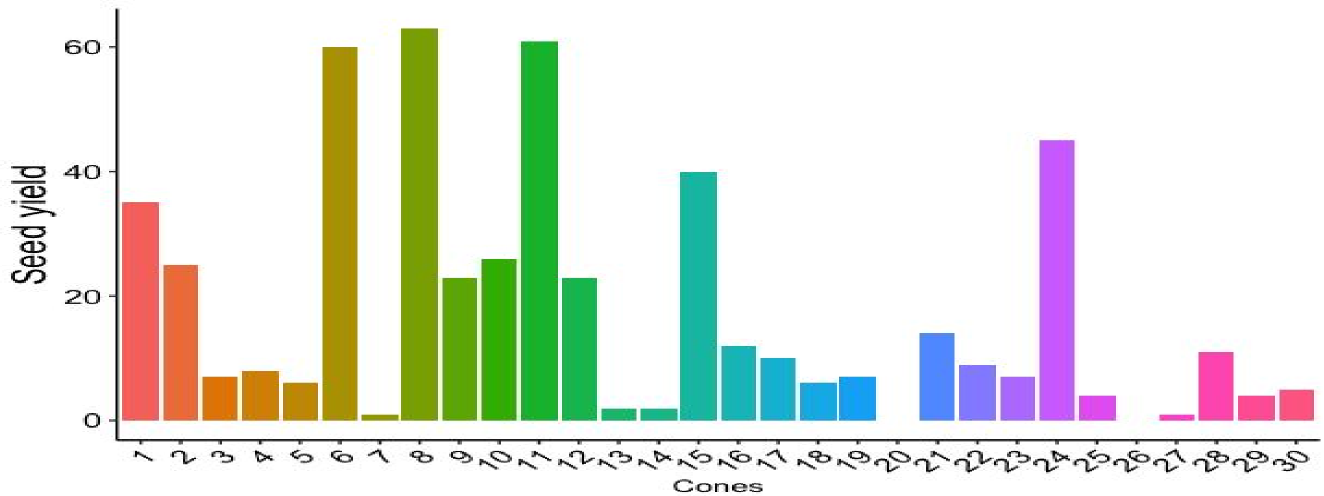

Figure 6: Cumulative seed yield of individual light cones exposed to natural drying in seed extraction beds up to 21 days

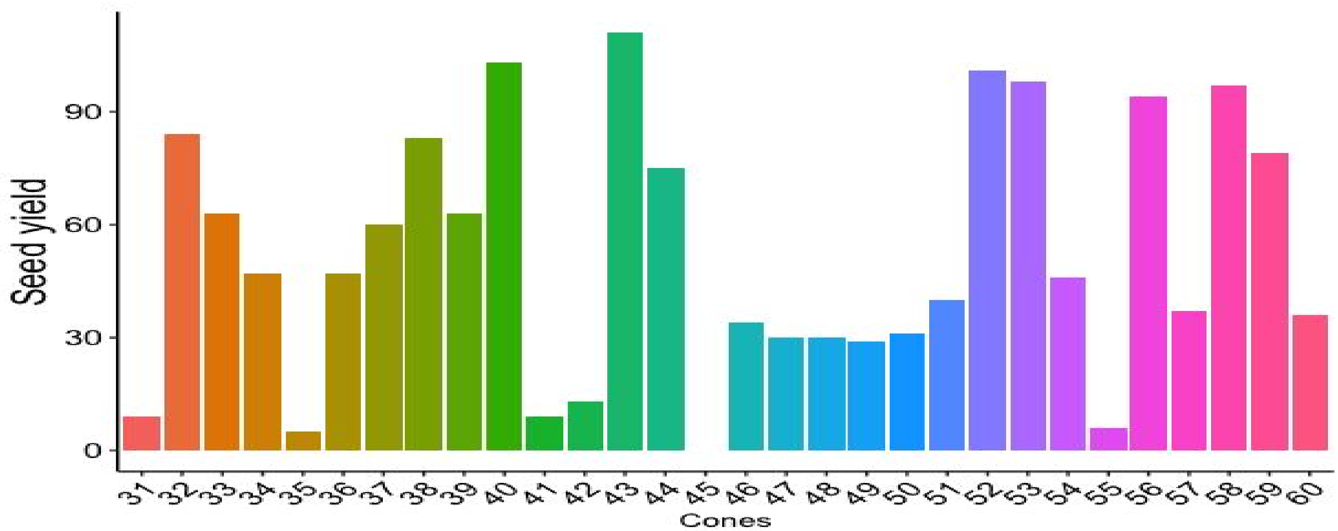

Figure 7: Cumulative seed yield of heavy cones exposed to natural drying in seed extraction beds up to 21 days

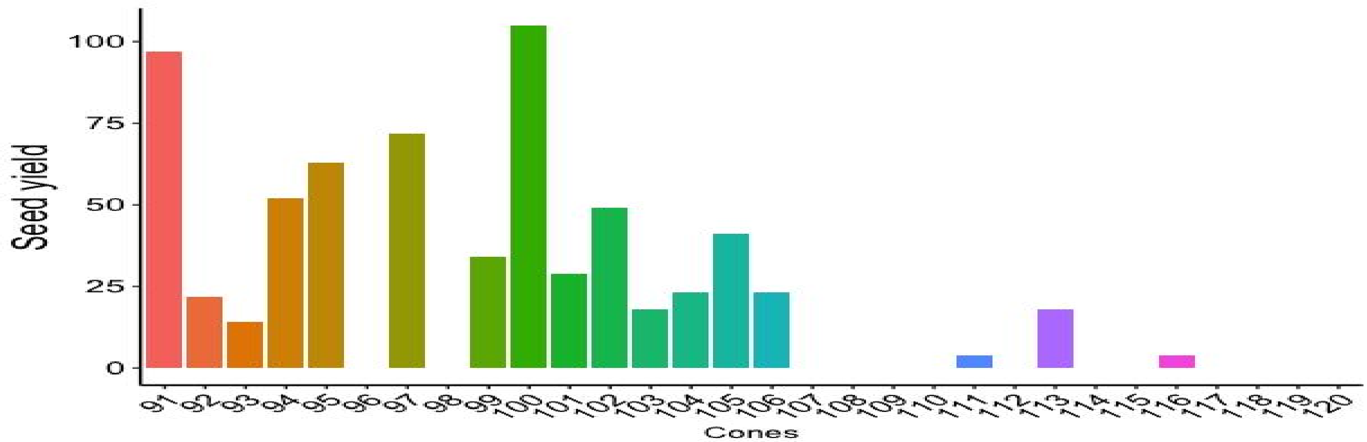

Figure 8:Cumulative seed yield of individual narrow cones exposed to natural seed extraction for up to 21 days

Narrow cones exposed to natural dying for seed extraction were observed to experience more delays in the opening as this category had the highest number of cones, 13 out of 30, that had not opened for seed releasebythe end of the 21 days. However,the light cones had the overall lowest mean cumulative seed yield. The observed mean number of seeds in each category wasLDB=17±0.02 HDB=52±0.04 and NDB=22±0.04 (Fig. 8)

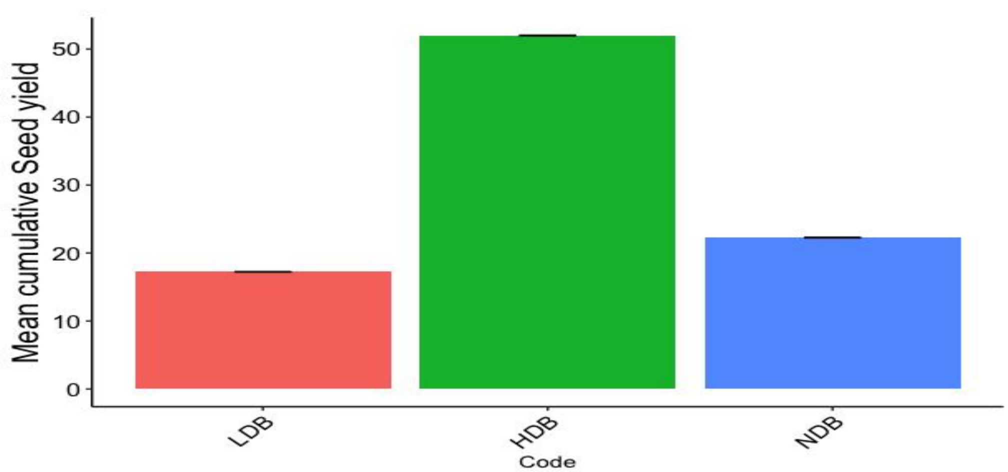

Figure 9:Mean cumulative seed yield of light (LDB), heavy (HDB), and narrow (NDB) cones exposed to natural seed extraction in drying beds.

Conclusions

In this study, there is a positive correlation between cone width, cone weight, and tree DBH with any increase in diameter having a positive effect on the cone size and weight. This study showed that for *P. patula*, cone width had a greater influence on the amount of seed release than cone weight. When considering efficiency in mechanized seed extraction, the first six hours were shown to be optimum for seedrelease. Thus, cone sorting for wider cones for extraction at 65^{o}C forat least six hours would yield a greater part of the seeds in artificially heated timed kilns.

Acknowledgment

The authors are grateful to the Kenya Forestry Research Institute's management and staff for the support accorded during the entire process of this work.

Conflict of interests

The authors have not declared any conflict of interest.

References

1. Owino F, Ndinga A. Study on forest administration and related institutional arrangements. Lessons Learn Sustain For Manag Africa. 2004.

2. Donald DGM. Dormacy control in pinus patula seed. South African For J. 1981;118(1):14–9.

3. Aniszewska M. Analysis of opening cones of selected coniferous trees. In: Annals of WULS, Forestry and Wood Technology [Internet]. 2010. p. 57–64. Available from: http://annals-wuls.sggw.pl/files/files/afe2010no55full.pdf#page=57

4. Lixia H, Cuicui LI, Jihong Q. Comparison of the Physicochemical Characteristics of Pinus

koraiensis L. Nut Oils from Different Extraction Technologies. Grain Oil Sci Technol. 2018;1(3):113–8.

5. Singh A, Husain M, Mir RA, Parrey AA, Paddar NA. Effect of different seed extraction methods for rapid extraction of seeds from the cones of Aleppo pine (Pinus halepensis) under controlled conditions in Kashmir Valley, India. Pharmacogn Phytochem. 2017;6(4):1622–5.

6. Zhao Q, Qin J, Wang H, Wang J, Zhang X. Effects of different extraction methods on the properties of pine cone polysaccharides from Pinus koraiensis. BioResources. 2019;14(4):9945–56.

7. Richardson DM, Williams PA, Hobbs RJ. Pine Invasions in the Southern Hemisphere: Determinants of Spread and Invadability. J Biogeogr. 1994;21(5):511.

8. Kanzler A, Nel A, Ford C. Development and commercialisation of the Pinus patula × P. tecunumanii hybrid in response to the threat of Fusarium circinatum. New For. 2014;45(3):417–37.

9. Valera FP, Kageyama PY. Pinus patula, Schiede & Deppe. Danida Forest Seed Centre DK-3050 Humlebæk,Denmark; 2020. (0902-3216; vol. Seedleafle).

10. Moya D, Espelta JM, Verkaik I, López-Serrano F, De Las Heras J. Tree density and site quality influence on Pinus halepensis Mill. reproductive characteristics after large fires. Ann For Sci. 2007;64(6):649–56.

11. Tapias R, Gil L, Fuentes-Utrilla P, Pardos JA. Canopy seed banks in Mediterranean pines of southeastern Spain: A comparison between Pinus halepensis Mill., P. pinaster Ait., P.

nigra Arn. and P. pinea L. J Ecol. 2001;89(4):629–38.

12. Perry DA, Lotan JE. Opening temperatures in serotinous cones of lodgepole pine [Internet]. Utah: U.S. Department of Agriculture, Forest Service; 1977. 1–8 p. Available from: https://books.google.com/books?hl=en&lr=&id=8wGKkTLJNboC&oi=fnd&pg=PA3&dq=These+variations+could+be+attributed+to+cone+morphology,+varying+degrees+of+asymmetry,+differences+in+scale+tension,+effect+of+environment+on+bonding+strength,+and+genetic+differenc

13. Wyse S V, Brown JE, Hulme PE. Seed release by a serotinous pine in the absence of fire: implications for invasion into temperate regions. AoB Plants. 2019;11(6):1–8.

14. Tapias R, Climent J, Pardos JA, Gil L. Life Histories of Mediterranean Pines. Plant Ecol. 2016;171(1):53–68.

15. Angaine PM, Onyango AA, Ndungú SM, Inoti SK, Owino JO. Influence of Cupressus lusitanica Mill. cones and seed characterization on germination in Kenya. J For. 2021;8(2):123–30.

16. Onyango AA, Angaine PM, Mbinga J, Owino JO. Variations in Cupressus lusitanica Mill . Seed Yield and Quality under Different Extraction Conditions in Kenya. 2021;7(1):1–10.

17. Onyango AA, Angaine PM, Inoti SK, Owino JO. Patula pine (Pinus patula) cones opening under different treatments for rapid seed extraction in Londiani , Kenya. J Hortic For. 2020;12(June):63–9.

18. Jaouadi W, Naghmouchi S, Alsubeie M. Should the silviculture of Aleppo pine (Pinus

halepensis Mill.) stands in northern Africa be oriented towards wood or seed and cone production? Diagnosis and current potentiality. iForest [Internet]. 2019;12:297–305. Available from: https://iforest.sisef.org/

19. Tulska E, Aniszewska M. Comparison of thermal and thermomechanical methods of seed extraction from larch cones based on two case studies. Int Agrophysics. 2022;36(3):197–206.

20. Tulska E, Aniszewska M, Zychowicz W. Optimization of the process of seed extraction from the Larix decidua Mill. cones including evaluation of seed quantity and quality. Sci Rep [Internet]. 2022;12(1):1–15. Available from: https://doi.org/10.1038/s41598-022-22942-2

21. Ayari A, Moya D, Rejeb MN, Garchi S, de las Heras J. Fructification and species conservation on Pinus halepensis Mill forests in Tunisia: Managing structure using individual tree size. Pine For Types, Threat Manag. 2011;(May 2015):61–80.

22. Iwaizumi MG, Ubukata M, Yamada H. Within-crown cone production patterns dependent on cone productivities in Pinus densiflora: Effects of vertically differential, pollination-related, cone-growing conditions. Botany. 2008;86(6):576–86.

23. Harlow WM, W.A Cote J, Day AC. The Opening Mechanism of Pine Cone Scales. 2019;538–40. Available from: https://academic.oup.com/jof/article-abstract/62/8/538/4672307

24. Samano S, Tomback DF. Cone opening phenology, seed dispersal, and seed predation in southwestern white pine (Pinus strobiformis) in southern Colorado. Ecoscience. 2003;10(3):319–26.

25. Bramlett DL. Efficiency of Seed Production in Southern. In: Thirteenth Lake States Forest Tree Improvement Conference [Internet]. U.S. Department of Agriculture, Forest Service; 1977. Available from: https://www.fs.usda.gov/treesearch/pubs/14783

26. Reyes O, Casal M. Effect of high temperatures on cone opening and on the release and viability of Pinus pinaster and P. radiata seeds in NW Spain Otilia. Ann For Sci. 2001;64:219–28.

27. Essl F, Mang T, Dullinger S, Moser D, Hulme PE. Macroecological drivers of alien conifer naturalizations worldwide. Ecography (Cop). 2011;34(6):1076–84.

28. Gregorio N, Harrison S, Vanclay J, Bosch A. Enhancing tree seedling supply via economic and policy changes in the Philippines nursery sector [Internet]. Australian Centre for International Agricultural Research. Canberra; 2011 Feb. Available from: https://www.researchgate.net/profile/Jerome_Vanclay/publication/294848433_Enhancing_tree_seedling_supply_via_economic_and_policy_changes_in_the_Philippines_nursery_sector/links/56c44ef708aeeeffa9e5a681.pdf

29. Hellum AK, Pelchat M. Temperature and time affect the realease and quality of seed from cones of lodgepole pine from Alberta. Can J For Res. 1978;

30. Ghildiyal S, Sharma C, Gairola S. Effect of temperature on cone bursting, seed extraction and germination in five provenances of Pinus roxburghii from Garhwal Himalaya in India. South For a J For Sci [Internet]. 2008 Jul;70(1):1–5. Available from: http://www.tandfonline.com/doi/abs/10.2989/SOUTH.FOR.2008.70.1.1.511

31. KFS. Londiani Participatory Forest Management Plan. CIFOR; 2018.

32. Angaine PM, Onyango AA, Owino JO. Morphometrics of Pinus patula crown and its effect on cone characteristics and seed yield in Kenya. J Hortic For [Internet]. 2020 Jul 31;12(3):94–100. Available from: https://academicjournals.org/journal/JHF/article-abstract/EA3616F64129

33. Ayari A, Meftahi M, Zammeli F, Khouja M. Seed Production Variability of Aleppo Pine (Pinus Halepensis Mill.) within Korbus Arboretum (North East of Tunisia). Glob J Bot Sci. 2016;4(1):20–3.

34. Kaliniewicz Z, Tylek P, Markowski P, Anders A, Rawa T, Głażewska E. Analysis of correlations between selected physical properties and color of Scots Pine (Pinus sylvestris L.) seeds. Tech Sci. 2014;17(3):259–74.

35. Calama R, Montero G. Cone and seed production from stone pine (Pinus pinea L.) stands in Central Range (Spain). Eur J For Res. 2007;126(1):23–35.

36. Nieto De Pascual-Pola C, Musalem MÁ, Ortega-Alcalá J. Study of some characteristics of cones and seed of Abies religiosa (HBK) Schl. et Cham. Agrociencia. 2003;37(5):521–35.

37. Ayari A, Zubizarreta-Gerendiain A, Tome M, Tome J, Garchi S, Henchi B. Stand, tree and crown variables affecting cone crop and seed yield of Aleppo pine forests in different bioclimatic regions of Tunisia. For Syst. 2012;21(1):128.

38. Bravo F, Maguire DA, González-Martínez SC. Factors affecting cone production in Pinus pinaster Ait.: Lack of growth-reproduction trade-offs but significant effects of climate and tree and stand characteristics. For Syst. 2017;26(2).

39. Ayari A, Khouja ML. Tree Physiology review Ecophysiological variables influencing

Aleppo pine seed and cone production : a review. Tree Physiol. 2014;426–37.

40. Guemri R El, Jaouadi W, Mechergui K, Alsubeie M, Naghmouchi S, Ouellani S El, et al. Morphological characteristics and variation of wood, cone and seed productions in the reforestation of Aleppo pine in Northeastern Tunisia using terrestrial and spatial index approaches. Ekol Bratislava. 2019;38(3):273–91.

41. Iwaizumi MG, Ohtani M, Takahashi M. Geographic cline and climatic effects on cone characteristics of natural populations of Pinus densiflora throughout the Japanese archipelago. J For Res [Internet]. 2019;24(3):187–96. Available from: https://doi.org/10.1080/13416979.2019.1603666

42. Zhang Y, Hu P, Zhong C, Wei Y, Meng J, Li Z, et al. Analyses of genetic diversity, differentiation and geographic origin of natural provenances and land races of Casuarina equisetifolia based on EST-SSR markers. Forests [Internet]. 2020 Apr 10;11(4):432. Available from: www.mdpi.com/journal/forests

43. Fernando DD. The pine reproductive process in temperate and tropical regions. New For. 2014;45(3):333–52.

44. Rawat K, Bakshi M. Provenance variation in cone , seed and seedling characteristics in natural populations of Pinus wallichiana A . B . Jacks (Blue Pine) in India. 2011;54(1):39–55.

45. Tíscar PA. Geographical variation in cone traits of Pinus nigra as result of crossbill predation: Implications for assisted migration. Forestry. 2019;92(2):188–95.

46. Matziris D. Genetic variation in cone and seed characteristics in a clonal seed orchard of

Aleppo pine grown in Greece. Silvae Genet. 1998;47(1):37–41.

47. Weng YH, Liu KJ, Chen YB, Li Y, Wang J, Meng QF, et al. Variation in cone and seed traits in a clonal seed orchard of red pine (Pinus koraiensis Sieb . et Zucc .). 2020;7581.

48. Ganatsas P, Tsakaldimi M, Thanos C. Seed and cone diversity and seed germination of Pinus pinea in Strofylia Site of the Natura 2000 Network. Biodivers Conserv [Internet]. 2008 Sep 18;17(10):2427–39. Available from: http://link.springer.com/10.1007/s10531-008-9390-8

49. Bilir N, Prescher F, Lindgren D, Kroon J. Variation in cone and seed characters in clonal seed orchards of Pinus sylvestris. New For. 2008;36(2):187–99.

50. Sevik H, Topacoglu O. Variation and Inheritance pattern in cone and seed characteristics of Scots pine (Pinus sylvestris L.) for evaluation of genetic diversity. J Environ Biol. 2015;36(September):1125–30.

51. Hauke-Kowalska M, Borowiak E, Barzdajn W, Kowalkowski W, Korzeniewicz R, Wawro T. Cone and seeds variability in seed Orchards and seed stands of Pinus sylvestris. Balt For. 2019;25(2(50)):187–92.

52. Dylewski Ł, Jagodziński AM, Tomaś Ł, Myczko Ł, Flaherty S. Forest stand structure and cone crop affect winter habitat use by Eurasian red squirrel (Sciurus vulgaris). For Ecol Manage. 2021;502(September).

53. Bastien R, Ganteaume A. Correction to: Does recent fire activity impact fire-related traits of Pinus halepensis Mill. and Pinus sylvestris L. in the French Mediterranean area? (Annals of Forest Science, (2020), 77, 4, (106), 10.1007/s13595-020-01016-1). Ann For

Sci. 2020;77(4):1–19.

54. Garcillán PP. Seed release without fire in Callitropsis guadalupensis, a serotinous cypress of a Mediterranean-climate oceanic island. J Arid Environ [Internet]. 2010 Apr;74(4):512–5. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0140196309002973

55. Horstmann M, Buchheit H, Speck T, Poppinga S. The cracking of Scots pine (Pinus sylvestris) cones. Front Plant Sci [Internet]. 2022 Oct 18;13. Available from: https://www.frontiersin.org/articles/10.3389/fpls.2022.982756/full