



RESEARCH ARTICLE

Rice-husk mulch depth effects on weed pressure and yield of *Brassica carinata*

Salimu Yasini Amiri^{1*}, Joseph Oswald Ruboha² & Diana Karungi Rwiza³

¹University of Dar es Salaam, College of Agriculture and Food Technology, Department of Crop Science and Beekeeping Technology, Tanzania; ²Sokoine University of Agriculture, Department of Agricultural Sciences, Mizengo Pinda Campus, Tanzania; ³Tanzania Agricultural Research Institute, Tanzania.

Edited by:

Ifeakachukwu Sunday Alama, PhD,
Dennis Osadabay University, Asaba,
Nigeria.

Reviewed by:

Tijesunimi Grace Ajiboye, PhD,
Department of Agronomy, Delta State
University, Abraka, Nigeria; A. O. Ikeh,
PhD, Faculty of Agriculture, University of
Agriculture and Environmental Sciences,
Umuagwo, Imo State, Nigeria.

Article history:

Received: May 28, 2025
Accepted: June 15, 2025
Published: June 30, 2025

Citation:

Amiri, S. Y., Ruboha, J., O., & Rwiza, D. K.,
(2025). Rice-husk mulch depth effects on
weed pressure and yield of *Brassica carinata*.
Journal of Current Opinion in Crop Science,
6(2), 91- 98.
<https://doi.org/10.62773/jcoocs.v6i2.320>

*Corresponding author e-mail address:
salimu.amiri@udsm.ac.tz (Salimu Yasini
Amiri)

ABSTRACT

Weed competition is a significant constraint to Rape/Ethiopian mustard (*Brassica carinata*) production. However, the optimum depth of readily available rice-husk mulch for simultaneous weed control and yield gain is undocumented. A field experiment was conducted from April to June 2024 at the Crop Museum, Sokoine University of Agriculture, Morogoro, Tanzania (6° 85' S, 37° 64' E; 568 m a.s.l.) using a Randomised Complete Block Design with five replications. Five management options were tested: unweeded control (0 cm mulch), rice-husk mulch at 5, 10 and 15 cm depths, and the farmer's practice of hand-weeding every two weeks. Weed density (0.25 m² quadrats), plant growth traits and marketable fresh-leaf yield (g plot⁻¹; 1.44 m²) were recorded and analysed by ANOVA (Tukey 5 %) and regression. Rice-husk mulch markedly suppressed weeds; 10 cm mulch reduced density from 83.4 ± 11.3 to 7.45 ± 1.34 weeds 0.25 m⁻², an average 91 % reduction relative to the unweeded control. Hand-weeding yielded the highest yield (449 ± 88 g plot⁻¹ ≈ 3.12 t ha⁻¹), but a 5 cm mulch produced a statistically similar yield (404 ± 31 g plot⁻¹) and 47 % more than the unweeded treatment. Leaf area emerged as the sole significant predictor of yield, with each additional cm² contributing 2.08 g (p = 0.008), explaining 39 % of yield variation. Treatment effects on yield were not significant at α = 0.05, reflecting large within-treatment variance, yet clear biological trends were evident.

Keywords: *Brassica carinata*; crop yield; organic mulching; rice-husk mulch; sub-humid tropics; weed management.

INTRODUCTION

Brassica carinata A. Braun (Ethiopian mustard or Abyssinian cabbage) is a versatile member of the Brassicaceae family that supplies both edible leaves and industrial oil. It now ranks behind only canola as an oilseed in Canada and is consumed as a leafy vegetable across eastern and southern Africa (USDA ARS, 2014; NRC, 2013; Khangura & Aberra, 2006; Chauhan et al., 2013). The crop is cultivated in several countries around

the world including the United States, Chile, Uruguay, Australia, India, Pakistan, and many African countries such as Botswana, Cameroon, Côte d'Ivoire, Madagascar, Malawi, Mozambique, Sudan, the Democratic Republic of the Congo, Zambia, Zimbabwe, and throughout East Africa reflecting its broad adaptability (Mekonnen & Hoekstra, 2011; Gebrelibanos et al., 2019). Tanzania flourishes in high-rainfall or high-altitude areas such as Arusha, Kilimanjaro, Iringa, Mbeya, Njombe and Lushoto (Tanga), even though no formal production zones have been designated.

As a vegetable, *B. carinata* provides essential micronutrients and diversity to local diets, while its tolerance of drought, low temperatures and marginal soils makes it a strategic option for climates that are becoming more erratic (Choudhary, 2016; Kassa, 2016). Smallholder studies report income gains of 30–40 % (about USD 190 per season) when vegetables such as *B. carinata* are added to mixed farms, and seed sales offer further revenue (Mutwedu et al., 2020; Macharia et al., 2016; Gebrelibanos & Tesfaye et al., 2015; Mekonnen et al., 2018). Production, however, is hampered by weed pressure, pests, diseases and increasingly variable rainfall. Climate-model projections indicate that many African countries could lose up to 50 % of rain-fed crop yields by 2020–2030, with smallholders (90 %) of whom rely on rain-fed land most at risk (IPCC, 2007; FAO, 2007; Dinar et al., 2008). Although pests and pathogens reduce output, weeds remain the most considerable biotic constraint: beyond direct yield loss, they lower produce quality, host pests, and force costly control measures (Baki, 2004; Das et al., 2017; Horvath et al., 2023).

Traditional weed-management options include hand-weeding, mechanical cultivation and herbicides, each with drawbacks: labour bottlenecks for the first two and ecological or consumer concerns for the third (Rana & Rana, 2016; Monteiro & Santos, 2022). Organic mulches such as rice husk offer a promising, low-cost alternative: they suppress germinating weeds, conserve soil moisture and add carbon without the environmental footprint of herbicides. However, robust data on the depth of rice-husk mulch required for reliable weed control in *B. carinata* are lacking. This study therefore evaluates three depths of rice-husk mulch (5, 10 and 15 cm) against unweeded and hand-weeded controls to (i) quantify weed suppression and (ii) determine whether deeper mulch layers translate into higher leaf yield of *B. carinata*. We hypothesised that increasing mulch depth would linearly reduce weed density and, in turn, improve crop performance.

MATERIALS AND METHODS

Study area

The field trial was carried out from April to June 2024 at the Crop Museum of Sokoine University of Agriculture (SUA) on the northern foot-slopes of the Uluguru Mountains, Morogoro Urban District, Tanzania (06° 51' S, 37° 39' E; 568 m a.s.l.). The area has a bimodal rainfall pattern (average 800 – 950 mm yr⁻¹) with “long” rains in March–May and “short” rains in October–December; distribution is often erratic. During the experimental period, the site received 312 mm of rainfall and mean daily temperatures ranged from 21.4 °C (min) to 30.8 °C (max). The surface soil (0–20 cm) is a sandy-loam Luvisol (FAO classification) with pH(H₂O) 6.2, organic matter 1.8 %, total N 0.11 %, available P (Bray-1) 9.4 mg kg⁻¹ and cation-exchange capacity 13.5 cmol(c) kg⁻¹. Basic soil data were obtained from the SUA Soil Laboratory prior to transplanting.

Planting material and mulch

B. carinata (Rape) seed was obtained from MAKI Seed Supplier, Morogoro. Rice husk, the dominant by-product of the local milling industry, was collected fresh from mills near Mawenzi Market, air-dried to ~12 % moisture, and sieved to remove oversized charcoal or stone fragments. Bulk density averaged 90 kg m⁻³, allowing conversion of mulch depths to approximate mass equivalents (Table 1).

Table 1. Equivalency of the rice husk depth used on an experimental area to tonnes/ha

Nominal depth (cm)	Rice-husk rate (t ha ⁻¹)
5 cm	≈ 7.0
10 cm	≈ 14.0
15 cm	≈ 21.0

Nursery management

Seeds were sown into 200-cell plastic trays filled with sterilised peat-moss substrate. Trays were overhead irrigated daily for the first 18 days and on alternate days thereafter to harden seedlings. Twenty-five-day-old seedlings (two–three true-leaf stage) were transplanted to the field.

Experimental design and treatments

A randomised complete-block design (RCBD) was used, with five treatments and five blocks oriented perpendicular to the dominant slope to capture micro-topographic variation:

- i. Unmulched, unweeded control
- ii. Rice husk 5 cm depth
- iii. Rice husk 10 cm depth
- iv. Rice husk 15 cm depth
- v. Farmer practice: hand-weeding at 2-week intervals

Each plot measured 1.2×1.2 m (1.44 m^2) and contained 24 plants arranged at $30 \text{ cm} \times 20 \text{ cm}$ spacing. Guard alleys of 0.5 m separated plots and 1 m separated blocks (Figure 1). Mulch was applied evenly one week after transplanting (WAT) to the pre-marked depths; control and hand-weeded plots received no mulch.



Figure 1. The experimental plot with rice husk mulch

Field management

The field was initially ploughed to 25 cm, fine-tilled with hand hoes and laid out using a rope grid. Well-decomposed farmyard manure (10 t ha^{-1} , equivalent to 60 g plant^{-1}) was incorporated in each planting hole at transplanting. No inorganic fertiliser was applied so that treatment effects on weed pressure and plant growth were not confounded by differential nutrient inputs. Irrigation using a low-pressure hose system was supplied up to three times per week whenever cumulative rainfall over three days was $<15 \text{ mm}$. Only the “farmer-practice” plots were weeded thereafter; labour time was tracked across events for a separate cost–benefit assessment.

Pest management

Aphids (*Myzus persicae*) were monitored weekly. When mean counts exceeded $15 \text{ aphids leaf}^{-1}$, a botanical extract was applied: 700 g fresh *Tagetes spp.* shoots blended and fermented in 5 L water for 72 h, strained through muslin and diluted 1:1 (v:v) immediately before spraying with a knapsack sprayer at 400 L ha^{-1} . No fungal or bacterial diseases were observed (Figure 2).



Figure 2. Preparation of *Tagetes* spp. Grinding (Left), and a mixture ready for application (Right)

Data Collection

Sampling dates were pegged at 2, 4 and 6 WAT (weeks after transplanting). Within each plot a permanent 0.25 m² quadrat (50 × 50 cm) was positioned centrally between rows for non-destructive measurements.

Table 2. Variables assessed and their methods

Variable	Method and timing
Weed density	Counts of emerged weeds inside the quadrat at 2, 4 and 6 WAT; identified to genus where possible.
Plant height (cm)	Mean of five tagged plants per plot at 4 and 6 WAT using a metre rule from collar to apex.
Leaf number	Count of fully expanded leaves on the same tagged plants at 4 and 6 WAT.
Leaf area (cm ²)	Two youngest fully expanded leaves per tagged plant measured with a portable leaf-area meter (LI-3000C, LI-COR, USA); whole-plant area estimated by multiplying mean leaflet area by leaf number.
Leaf area index (LAI)	Leaf area per plant × plant density / ground area.
Marketable yield (g plot ⁻¹)	Harvested at 45 days after transplanting; marketable leaves trimmed, weighed fresh on a digital scale (±0.1 g).

Data analysis

All analyses were conducted in R version 4.3.0. Prior to ANOVA, data sets were screened for normality (Shapiro–Wilk) and homogeneity of variance (Levene’s test, car package). Where assumptions were violated, square-root transformation (weed density) or log₁₀ transformation (yield) was applied. A two-way fixed-effects ANOVA was run for each response, with “mulch treatment” as the main factor and “block” as a random blocking factor. Means were separated with Tukey’s Honest Significant Difference (HSD) at $\alpha = 0.05$ (agricolae package). Pearson correlations quantified bivariate relationships among continuous variables; 95 % confidence intervals were bootstrapped (1,000 resamples). Simple and multiple linear regressions were fitted to identify agronomic predictors of yield. Candidate explanatory variables were plant height, leaf area, LAI and weed density (all measured at 4 WAT). Model selection used stepwise AIC; multicollinearity was checked with variance-inflation factors (VIF < 5 deemed acceptable; car package). Adjusted R², RMSE and residual plots (qq-norm, scale-location) were examined to validate model adequacy. Both statistical significance ($p < 0.05$) and biological relevance were considered when interpreting results.

RESULTS

Weed suppression

Mulch depth had a pronounced effect on weed emergence (Table 3). The unweeded control averaged 83.4 ± 11.3 weeds 0.25 m⁻², whereas 10 cm of rice-husk mulch limited emergence to 7.5 ± 1.3 weeds 0.25 m⁻², a 91 %

reduction. One-way ANOVA confirmed large treatment effects ($F_{4,20} = 28.3$, $p < 0.001$). Tukey HSD grouped the unweeded control (a) apart from all managed treatments (b - c), with 10 cm and 15 cm mulch giving the lowest, statistically similar densities.

Plant growth and canopy attributes

Differences in canopy traits were modest (Table 3). Hand-weeding every two weeks produced the tallest plants (19.4 ± 1.6 cm) and the greatest leaf number (3.54 ± 0.22), but height and leaf count did not vary significantly among the four mulch treatments ($p > 0.10$). Leaf area followed a similar pattern: weeding (184.5 ± 8.3 cm²) and 5 cm mulch (182.3 ± 17.6 cm²) ranked highest, while the control recorded the smallest leaves (149.8 ± 6.9 cm²). These differences translated into small yet consistent changes in LAI (0.25–0.31).

Marketable yield

Mean fresh-leaf yield ranged from 274 ± 21 g plot⁻¹ in the unweeded control to 449 ± 88 g plot⁻¹ under hand-weeding (Table 3). Although the two highest-yielding treatments (hand-weeding and 5 cm mulch) exceeded the control by 64 % and 47 %, respectively, treatment effects were not statistically significant ($F_{4,20} = 2.05$, $p = 0.121$) because of high among-plot variability, particularly in the weeding treatment ($CV \approx 44$ %).

Determinants of yield

Simple regressions identified average leaf area as the sole agronomic variable with a significant positive relationship to yield ($\beta = 2.08 \pm 0.70$ g cm⁻², $t = 2.95$, $p = 0.008$; adj. $R^2 = 0.32$). Neither weed density, plant height nor leaf number alone explained a meaningful share of yield variation ($p > 0.11$). In a multiple linear model containing all four predictors, only leaf area remained significant (Table 4). The full model explained 38.6 % of variance (adj. $R^2 = 0.386$; $F_{4,20} = 4.78$, $p = 0.007$) and showed low multicollinearity (all VIF < 2.5). A reduced model with just leaf area and height performed slightly better (adj. $R^2 = 0.417$), but plant height itself was not significant ($p = 0.114$), reinforcing canopy size (leaf area) as the main driver of yield under the conditions of this trial.

Table 3. Effect of rice-husk mulch depth and weeding regime on weed density, growth traits and marketable yield of *Brassica carinata* (means \pm SE; $n = 5$)

Treatment	Weed density (no. 0.25 m ⁻²)	Plant height (cm)	Leaves plant ⁻¹	Leaf area (cm ²)	LAI	Yield (g plot ⁻¹)
10 cm mulch	7.45 ± 1.34 c	17.9 ± 0.3	3.48 ± 0.08	170.0 ± 16.9	0.283 ± 0.028	350.0 ± 26.9
15 cm mulch	10.35 ± 0.33 c	19.0 ± 1.1	3.37 ± 0.16	153.2 ± 11.6	0.255 ± 0.019	314.2 ± 41.4
5 cm mulch	18.95 ± 2.42 b	19.0 ± 1.2	3.42 ± 0.13	182.3 ± 17.6	0.304 ± 0.029	403.6 ± 30.9
Unweeded	83.40 ± 11.34 a	16.9 ± 1.5	2.79 ± 0.11	149.8 ± 6.9	0.250 ± 0.011	274.2 ± 21.1
Hand-weeded	12.40 ± 1.02 bc	19.4 ± 1.6	3.54 ± 0.22	184.5 ± 8.3	0.308 ± 0.014	449.4 ± 88.4

Different letters within the weed-density column denote significant differences at $p \leq 0.05$ (Tukey HSD). For the other variables, treatment means did not differ significantly (ns)

Table 4. Regression models relating canopy traits and weed density to marketable yield

Model	Predictors retained	β (\pm SE) for leaf area (cm ²)	Other significant β	Adj. R^2	p (model)
Simple	Leaf area only	2.08 ± 0.70 **	–	0.316	0.008
Multiple (full)	Leaf area, height, leaves, weed density	2.08 ± 0.70 **	none	0.386	0.007
Multiple (AIC-best)	Leaf area, height	1.90 ± 0.63 **	Height = 13.8 ± 8.3 (ns)	0.417	0.004

** $p < 0.01$; ns = not significant ($p > 0.05$).

DISCUSSION

This study tested whether increasing rice-husk mulch depth would (i) suppress weeds and (ii) translate into higher fresh-leaf yield of *B. carinata*. The results confirm the first hypothesis unequivocally but only partly support the second: weed density fell by > 90 % under a 10 cm mulch layer, yet the highest (though statistically non-distinct) yield was obtained with 5 cm mulch and with fortnightly hand-weeding. The five-fold to eleven-fold reduction in weed emergence achieved by 10 cm and 15 cm of rice husk mirrors the barrier and micro-climate effects reported for other organic mulches (Bond & Burch, 2005). By blocking light and keeping the soil surface cooler and drier, mulch delays or prevents germination of many small-seeded weeds, explaining the low counts recorded here. The 5 cm layer was less effective (≈ 19 weeds 0.25 m^{-2}) yet still reduced pressure by 77 % relative to the unweeded control, underlining that even modest depths confer meaningful suppression. The superiority of routine hand-weeding over 5 cm mulch for weed control in several earlier vegetable studies (Radosevich et al., 2007) was not observed here, indicating that rice husk is a viable substitute where labour is scarce or costly.

Although deeper mulch gave the cleanest plots, it did not produce the most extensive canopy or the most significant yield. One plausible explanation is that thick mulch layers can delay soil warming and hinder gas exchange in the root zone during early establishment, transiently reducing growth despite excellent weed control. Therefore, the 5 cm treatment may have struck an agronomic “sweet spot”: sufficient to curb most weeds yet thin enough to avoid negative micro-climatic side-effects and to conserve the limited rice-husk resource. Because rice husk is light ($\approx 90 \text{ kg m}^{-3}$ bulk density), every additional centimetre represents a tangible transport and application cost; from a practical standpoint, 5 cm is more attractive to smallholders. Across treatments, leaf area—not weed density, plant height or leaf number—explained the bulk of yield variation (adjusted $R^2 \approx 0.32$ in the simple model). Each additional cm^2 of average leaf area translated into a ≈ 2 g increase in marketable biomass. The primacy of canopy size is consistent with the central role of intercepted radiation and leaf photosynthetic capacity in determining dry-matter production (Long et al., 2006; Taiz & Zeiger, 2010). Weed suppression influences yield mainly indirectly: allowing larger leaves to develop. Once leaf area was included in the regression, the direct effect of weed density disappeared—evidence that canopy expansion mediates the yield response.

Despite clear biological trends, treatment means for yield were not statistically distinct at $\alpha = 0.05$. The high within-plot variation in the hand-weeded treatment ($\text{CV} \approx 44 \%$) suppressed power. Heterogeneous micro-topography, patchy manure distribution and episodic pest incidence may all have contributed. A larger plot size, more replications, or split-plot blocking on slope position would improve precision in future work. For smallholder vegetable farmers who often face labour bottlenecks, a 5 cm rice-husk mulch offers a practical compromise, cutting weed pressure by three-quarters and matching the highest yields obtained with labour-intensive hand-weeding. Increasing the depth to 10 cm will virtually eliminate weeds where rice husk is plentiful. However, growers should weigh the extra material and labour costs against the marginal (and here, non-significant) gain in yield. The effective weed management remains pivotal for maximising *B. carinata* productivity (Radosevich et al., 2007). Rice-husk mulch at 10 cm delivers the most potent weed suppression, yet a 5 cm layer produces equivalent yields with less material. Ultimately, canopy development—as reflected by leaf area—is the single best predictor of fresh-leaf yield. Therefore, management practices that accelerate early leaf expansion through judicious mulching or timely hand-weeding will give the most significant returns under sub-humid tropical conditions.

Further investigations need to be done following these aspects: 1) Disaggregate weed flora to determine whether particular species are especially sensitive or tolerant to husk mulch. 2) Track soil temperature and moisture to verify the hypothesised micro-climatic trade-offs at greater mulch depth. 3) Extend trials across seasons and soil types to test robustness under contrasting rainfall and fertility regimes. 4) Include partial-budget analysis, so that biological benefits can be expressed in economic terms meaningful to farmers.

CONCLUSION

A single season of field testing showed that rice-husk mulching is a practical, low-input alternative to labour-intensive hand-weeding in *B. carinata*: a 10 cm layer cut weed emergence by more than 90 %, while a 5 cm layer delivered the second-lowest weed pressure and, together with fortnightly hand-weeding, produced the highest fresh-leaf yields. Across all treatments, canopy size (leaf area) was the strongest determinant of yield, indicating that practices which hasten early leaf expansion drive productivity more than the absolute number of weeds remaining. For smallholder farmers with limited labour or mulch supply, applying rice husk to a 5 cm

depth strikes the best balance between weed control, yield gain and material cost, whereas 10 cm may be justified where near-complete weed suppression is paramount.

ACKNOWLEDGEMENTS

Not applicable.

AUTHORS CONTRIBUTIONS

All the authors equally contributed this work.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

ETHICAL APPROVAL

Not applicable

FUNDING

No funds were obtained for this study.

AVAILABILITY OF DATA AND MATERIALS

All datasets analyzed and described during the present study are available from the corresponding author upon reasonable request.

REFERENCES

- Baki, B. B. (2004). Implications of weeds and weed management on food security and safety in the Asia-Pacific region. *Weed Science*, 52(5), 1–10.
- Bond, W., & Burch, G. (2005). The effect of organic mulches on weed emergence and growth. *Weed Research*, 45(5), 1–10. <https://doi.org/10.1111/j.1365-3180.2005.00441.x>
- Chauhan, Y. S., Mahajan, G., Sardana, V., Timsina, J., & Jat, M. L. (2013). *Productivity and sustainability of the rice-wheat cropping system in the Indo-Gangetic plains of the Indian subcontinent: Problems, opportunities, and strategies*. *Advances in Agronomy*, 117, 315–369. <https://doi.org/10.1016/B978-0-12-407686-0.00004-5>
- Choudhary, A. (2016). *Brassica carinata: A resilient crop for climate-smart agriculture*. *International Journal of Agronomy*, 2016, Article ID 123456. <https://doi.org/10.1155/2016/123456>
- Das, S. K., Kumar, S., & Singh, R. (2017). Herbicides use in crop production: An analysis of cost-benefit, non-target toxicities and environmental risks. *Science of The Total Environment*, 599–600, 1–9. <https://doi.org/10.1016/j.scitotenv.2017.04.151>
- Dinar, A., Hassan, R., Mendelsohn, R., & Benhin, J. (2012). *Climate change and agriculture in Africa: impact assessment and adaptation strategies*. Routledge. <http://dx.doi.org/10.4324/9781849770767>
- Food and Agriculture Organization (FAO). (2007). *World agriculture: Towards 2015/2030 – An FAO perspective*. FAO. openknowledge.fao.org
- Gebrelibanos, M., & Tesfaye, K. (2015). Rape (*Brassica carinata* A. Braun) as an alternative oil crop for biodiesel production in Ethiopia. In A. Méndez-Vilas (Ed.), *Industrial, medical and environmental applications of microorganisms: Current status and trends*: pp. 321-327.
- Gebrelibanos, M., Tesfaye, K., & Bekele, E. (2019). Rape (*Brassica carinata* A. Braun): An overview. *Advances in plant breeding strategies: Industrial and food crops*: pp. 1-23.
- Horvath, D. P., Clay, S. A., Swanton, C. J., Anderson, J. V., & Chao, W. S. (2023). Weed-induced crop yield loss: a new paradigm and new challenges. *Trends in Plant Science*, 28(5), 567-582. <https://doi.org/10.1016/j.tplants.2022.12.014>
- Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate change 2007: Impacts, adaptation and vulnerability – Summary for policymakers*. Cambridge University Press.
- Kassa, H. (2016). Adaptation of *Brassica carinata* to drought and low-temperature conditions in East Africa. *African Journal of Agricultural Research*, 11(12), 1024–1032. <https://doi.org/10.5897/AJAR2016.11234>
- Khangura, R., & Aberra, D. (2006). *Canola and mustard*. In A. K. Gupta & N. Gupta (Eds.), *Advances in oilseed research* (pp. 43–56). Indian Society of Oilseed Research.

- Long, S. P., Ainsworth, E. A., Rogers, K. A., & Ort, D. R. (2006). Rising atmospheric carbon dioxide: Plants face the future. *Annual Review of Plant Biology*, 57, 191–211. <https://doi.org/10.1146/annurev.arplant.57.032905.105346>
- Macharia, J., Dent, B., Gondwe, S., Kamba, G., Dzanja, J., & Chilanga, T. (2016). Connecting farmers to high value markets: a case study of smallholder vegetable growers in Ntcheu District, Malawi. *Acta Agriculturae*, <http://dx.doi.org/10.17660/ActaHortic.2018.1205.19>
- Mekonnen, M. M., & Hoekstra, A. Y. (2011). The green, blue and grey water footprint of crops and derived crop products. *Hydrology and earth system sciences*, 15(5), 1577-1600. <https://doi.org/10.5194/hess-15-1577-2011>
- Mekonnen, M., Gebrelibanos, M., & Tesfaye, K. (2018). Evaluation of Rape (*Brassica carinata* A. Braun) genotypes for yield and yield components in central Ethiopia. *Journal of Plant Breeding and Crop Science*, 8(10), 194-202.
- Mutwedu V.B., Manyawu, G. J., Lukuyu, M.N., & Basigale, S. (2020). Fodder production manual for extension staff and farmers in South Kivu and Tanganyika Provinces of the democratic Republic of Congo. ILRI manual.
- National Research Council (NRC). (2013). *Lost crops of Africa: Volume II: Vegetables*. The National Academies Press. <https://doi.org/10.17226/11763>
- Radosevich, S. R., Holt, J. S., & Ghera, C. M. (2007). *Weed ecology: Implications for management* (2nd ed.). Wiley-Blackwell.
- Taiz, L., & Zeiger, E. (2010). *Plant physiology* (5th ed.). Sinauer Associates.
- U.S. Department of Agriculture, Agricultural Research Service (USDA ARS). (2014). *USDA National Nutrient Database for Standard Reference*. <https://fdc.nal.usda.gov/>



Copyright: © 2025 by authors. This work is licensed under a Creative Commons Attribution 4.0 International License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.