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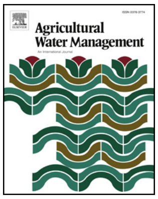

Nutritional water productivity of selected leafy vegetables

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ABSTRACT

The major challenge affecting rural resource-poor households (RRPHs) in South Africa is deficiencies in micronutrients (iron and zinc) and vitamin A. Traditional leafy vegetables (TLVs) are dense in iron, zinc, and β-carotene concentrations. Therefore, they are deemed suitable to improve the dietary diversity of RRPHs. The main objective of this study was to assess the effect of irrigation regimes on nutritional water productivity (NWP) of selected leafy vegetables [*Amaranthus cruentus* (Amaranth) and *Cleome gynandra* (Spider flower), both TLVs, and *Beta vulgaris* (Swiss chard)]. Experiments were conducted under a rain shelter at the ARC-VOP, Pretoria, South Africa, during two consecutive seasons (2013/14 and 2014/15). Leafy vegetables were subjected to three irrigation regimes [well-watered (I_{30}), moderate water stress (I_{50}), and severe water stress (I_{80})]. Data collected [(aboveground biomass (AGB), aboveground edible biomass (AGEB), actual evapotranspiration, and nutrient concentrations (iron, zinc and β-carotene)] were used to calculate NWP of leafy vegetables. Swiss chard exhibited a higher portion of AGEB compared to TLVs due to its larger harvest index (0.57-0.92). Selected TLVs displayed superiority in terms of nutrient richness compared to Swiss chard, under I_{50}. Results indicated that TLVs could provide more than the daily-recommended nutrient intake (DRNI) for vitamin A to all age groups. For iron, Spider flower could supply more than the DRNI to infants between 1 and 3 years of age, whereas for zinc, it could supply approximately 11% to this age group. However, higher micronutrient and β-carotene concentrations did not translate to superior nutritional yield (NY). Swiss chard showed higher Fe-NY and Zn-NY, whereas TLVs were rich in β-carotene-NY. Similarly, Swiss chard demonstrated the highest Fe-NWP (1090 mg m^{-3}) and Zn-NWP (125 mg m^{-3}), whereas Amaranth was larger in β-carotene-NWP (1799 mg m^{-3}), under moderate water stress. These results show that there may be an opportunity to improve NWP under drought conditions. There is a need for future studies that will assess NWP for a wider range of leafy vegetables. These studies should be conducted in different locations and explore the effect of management factors (fertiliser, water stress, planting density and planting date), and soil type on NWP of micronutrients and β-carotene.

1. Introduction

In South Africa, nearly fourteen million rural resource-poor households (RRPHs) have diets deficient in essential micronutrients (iron and zinc) and vitamin A (Oelofse and Van Averbeke, 2012). Thirty-four per cent of RRPHs rely on agriculture; therefore, this remains the main vehicle that can address food and nutrition insecurity (Mabhaudhi et al., 2016a). Govender et al. (2017) defined food and nutrition insecurity as the inability to access adequate quantities of nutritious foods required for optimal growth and development. Hendriks et al. (2016) found that in South Africa, one in four RRPHs experienced food and nutrition insecurity, which became severe in winter months (May-October) due to lack of water for irrigation. A typical diet of many RRPHs consisted of maize meal with sugar, and where income permitted, RRPHs consumed a relish of onions and tomato or cabbage once per day. Another study conducted by Wenhold et al. (2012) found that 50% of RRPHs consumed a diet including fewer than four food groups per day. This highlights that food and nutrition insecurity is persistent in rural areas of South Africa. Over the past decades, some progress has been made in addressing issues around food insecurity. However, most attention has been given to promote mainstream crops [Zea mays (maize), *Oryza sativa* (rice), *Triticum aestivum* (wheat), *Solanum tuberosum* (Irish potato), *Arachis hypogaea* (groundnut), and *Phaseolus vulgaris* (beans)] and selected vegetables [*Brassica oleracea* (cabbage),

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Daucus carota (carrot), *Allium cepa* (onion), *Lactuca sativa* (lettuce) and *Spinacea oleracea* (spinach)] to address food and nutrition security, underwater scarcity (Chibarabada et al., 2017; Mabhaudhi et al., 2016a,b). Minimal attention has been given towards addressing nutritional goals, especially for RRPHs.

We recognize the crucial role played by mainstream crops in providing proteins and calories. However, mainstream crops are deficient in essential micronutrients (iron and zinc) and β-carotene. Deficiency of micronutrients and vitamin A in human diets causes "hidden hunger"; a condition whose effects may not be immediately apparent, but may have severe consequences by inducing stunted growth, delayed cognitive development, and reduced immunity (Mabhaudhi et al.,2016a). To broaden the food basket of rural poor South Africans, the Water Research Commission has directed considerable funding towards research on traditional leafy vegetables (TLVs); i.e. vegetables that have adapted in a certain geographic location, where they have become part of local culture and indigenised (Mabhaudhi et al., 2017). Popularity of TLVs is attributed to their high nutrient concentration (iron, zinc, and β-carotene), their short crop cycle, the low use of agronomic inputs (water and fertiliser), their drought tolerance, and their abundance (available for RRPHs) in the "wild" or next to cereal crops as "weeds" (Chibarabada et al., 2017; Chivenge et al., 2015; Maseko et al., 2017; Mavengahama et al., 2013; Nyathi et al., 2016; Oelofse and Van Averbeke, 2012). It is important to note TLVs cannot replace mainstream crops in the diets of RRPHs; however, TLVs can contribute significantly to dietary diversity and agro-biodiversity (Chibarabada et al., 2017).

Chibarabada et al. (2017) noted that there is a gap between water use in agriculture, crop production, and nutritional requirements. From research conducted by nutritionists on nutrient concentrations of crops, daily consumption targets to meet human nutritional requirements can be derived (Uusiku et al., 2010; Van Jaarsveld et al., 2014; Schönfeldt and Pretorius, 2011). Agronomic and irrigation research tends to focus on producing as much crop with minimum water as possible (i.e. improving crop water productivity) (Chibarabada et al., 2017; Mabhaudhi et al., 2016a,b; Nhamo et al., 2016; Renault and Wallender, 2000). These three aspects (water use in agriculture, crop production, and nutritional requirements) cannot be assessed in isolation, because they interlink (Mabhaudhi et al., 2016b). Mabhaudhi et al. (2016a) averred that *"to meaningfully address food and nutrition security, there is a need for an index that combines aspects of water use, crop production, human nutrition, and food access."* They proposed the nutritional water productivity index (NWP) [NWP = (Yield or biomass/actual evapotranspiration) × nutritional content of a product)], which was coined by Renault and Wallender (2000). We fully support the suggestion of using the NWP index for assessing the relationship between water use, food production, and nutrition. However, this index can only be optimised for RRPHs if suitable crops that are highly nutritious (rich in iron, zinc, and β-carotene) are available to RRPHs, and data on their production requirements, consumption, and nutritional values are available to be incorporated in NWP assessments.

Information on NWP of TLVs is minimal. A scoping study conducted by Wenhold et al. (2012) benchmarked NWP of selected vegetables [(Amaranth (*Amaranthus cruentus*), Chinese cabbage (*Brassica rapa*), Spider flower (*Cleome gynandra*), Swiss chard (*Beta vulgaris*), cowpea (*Vigna unguiculata*), jute (*Corchorus* spp.), bitter watermelon (*Citrullus lanatus*), blackjack (*Bidens pilosa*), pumpkin leaves (*Cucurbita maxima*), sweet potato leaves (*Ipomoea batatas*), and kale (*Brassica oleracea* var. *sabellica*)] using datasets (yield or biomass, evapotranspiration, and nutrient concentration) derived from different literature sources. These parameters not only differ among crops, they also vary among different locations for the same crop due to climatic conditions, soil fertility, and water availability. This is a severe limitation to this data, as crop comparisons for these agronomic and nutritional factors are only valid when they are grown under the same conditions (Uusiku et al., 2010). The main aim of the study was to assess the effect of irrigation regimes on NWP of Amaranth, Spider flower, and Swiss chard using datasets (yield or biomass, evapotranspiration, and nutrient content) from the same location. The two TLVs (Amaranth and Spider flower) were selected because they are nutrient dense (high mass concentrations of iron, zinc, and β-carotene), and they are utilised by RRPHs as a relish in South Africa (Mavengahama et al., 2013). In this study, we compared NWP of selected TLVs with that of Swiss chard (var. *Fordhook Giant*). We selected Swiss chard because it is an alien leafy vegetable that is highly nutritious (contains high levels of Fe, Zn and β-carotene), has been commercialised many decades ago, and is widely consumed in sub-Saharan Africa as a relish with maize porridge (Mavengahama et al., 2013). For these selected TLVs and Swiss chard, we imposed three water stress levels and measured selected plant parameters [leaf area index, stomatal conductance, light interception, radiation use efficiency, biomass (above ground growth and above ground edible biomass), nutritional yield, and water productivity]. Our hypotheses were that: (1) TLVs are more tolerant to water stress than Swiss chard; (2) TLVs are more nutrient dense (iron, zinc, and β-carotene) than Swiss chard; and (3) TLVs are more productive than Swiss chard in terms of aboveground biomass, NY, and NWP under severe water stress.

2. Materials and methods

2.1. Experimental site description, set up, and crop management

Experiments were conducted under a rainshelter, at the Agricultural Research Council-Vegetables and Ornamental Plants (ARC-VOP), located in Roodeplaat, Pretoria (25° 59″ S; 28° 35″ E; 1168 m a.s.l.), in the Gauteng Province of South Africa, during the 2013/14 and 2014/15 summer seasons (November – May). The rainshelter has a rain sensor that activates an electric motor during a rainfall event and the shelter closes and covers the experimental field. Therefore, the experiment experiences normal field conditions, except when it is raining (Mabhaudhi et al., 2014). Nyathi et al. (2018) presented the long-term climatic data (rainfall, maximum and minimum temperatures), detailed meteorological conditions [maximum and minimum temperatures (°C), total radiation (MJ m^{-2}), reference evapotranspiration (mm day^{-1}), wind speed (m s^{-1}), and vapour pressure deficit (kPa)] during the growing seasons, and soil type of the experimental site, which was classified as a sandy loam using the USDA soil classification system

Table 1

Chemical soil properties for the experimental site.

Depth (cm)	Chemical properties						
	Fe mg kg^{-1}	Zn mg kg^{-1}	N-NO_3 mg kg^{-1}	N-NH_4 mg kg^{-1}	pH(H_2O)	K mg kg^{-1}	P-Bray 1 mg kg^{-1}
2013/14							
0-30	19.8	10.7	15.5	7.9	7.3	192	78
30-60	52.3	4.3	3.3	4.7	7.3	86	16
2014/15							
0-30	13.7	5.1	26.5	3.5	6.0	156	76