Unlocking the financial potential of growing fish and vegetables in South Africa: a systematic review of price trends

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Abstract. Aquaponics is the co-culture of fish and plants (vegetables) and thus provides two profit stations from fish and plants. Numerous economic models run at the University of KwaZulu-Natal and other published work show that vegetables offer 90% of the profitability rather than fish. Vegetable pricing is not constant and is subject to market demands and fluctuations and to maximize profitability from vegetable sales a historical trend analysis of pricing is needed. We conducted a systematic literature review to analyse six years of average monthly prices of vegetables. We then combined this data with literature of vegetables grown in aquaponics systems, comparing planting times, densities and yield, to determine when producers can attain maximum profit. This was done as a mechanism to maximize returns on investment. Pricing data was extracted from the Department of Agriculture, Land Reform and Rural Development, which is based on the primary data from 19 fresh produce markets in South Africa. The analysis of this data showed that the market price of vegetable crops may be influenced by the production volumes or other related costs. Meanwhile, other crops showed no correlation between market price and production volumes. This analysis also demonstrated that besides the market price and the growing periods of crops, other dynamic factors to consider in the efforts to produce a particular crop involve yield and density of the plant. On that basis, the analysis hence, demonstrated that *Ocimum basilicum* was significantly (ANOVA, F (11, 60) = 0.86, $p < 0.0001$) a better vegetable that could relatively offer maximum returns upon investments on its production, should it be grown during February to March over a shorter period of ≤ 2 months. The higher profitability of *O. basilicum* observed was also shown in the forecasting model used. Following *O. basilicum*, *Spinacia oleracea* could serve as a reasonable alternative to *O. basilicum* due to its significant results observed (ANOVA, F (11, 60) = 0.99, $p < 0.0001$). This paper provides insights on the price peak times of vegetables aligned with the best growing times for producers to derive maximum profits from the investments injected into the production. Some of the important aspects to consider in appraising the value of the vegetable crop are underscored.

Key Words: aquaponics, fresh produce market prices, growing times, market price, return on investment, vegetables in aquaponics.

Introduction. The world's population is growing faster than the rate of food production (FAO 2017), posing challenges in food supply and distribution to meet rising demand (Oladimeji et al 2020). The rising population and income levels in emerging economies are expected to increase food consumption in the coming decades. In contrast to the current global population of seven billion people, the world's population is expected to reach nine billion people by 2050 (Hagos & Hadush 2016; Delaide et al 2017). Thus, this rapid population growth projection is expected to result in a dramatic increase in food consumption demand against the global economic aspect (Hagos & Hadush 2016). Some scientific forecasts of intellects have observed an increase in the prices of stable consumer items, vegetables, and livestock outputs (Demeke et al 2009; FAO et al 2011). This could align to different factors involved in the production costs, such as water (Verdegem 2013). As such, to address these challenges and hence promote food production sustainability, researchers state that the future of farming is therefore embedded in low portions of land requirement systems, less water, and low carbon (Oladimeji et al 2020; Klinger & Naylor 2012; Verdegem 2013).

Aquaponics is consequently deemed as a sustainable food manufacturing technology due to its efficiency and environmentally sustainable farming method, which includes aquaculture and hydroponics in an integrated system (Danner et al 2019; Gosh & Chowdhury 2019). This incorporation represents a symbiotic interplay, whereby each of the embodied constituents presents advantages to the other (Gosh & Chowdhury 2019). Fish discharge nutrients into the water that provide nutrition for the growth of plants while plants eliminate composites such as ammonia that may adversely impact the heath and growth of fish (Danner et al 2019). Johnson et al (2017) stated that it is a tradition that aquaponics has combined recirculating aquaculture system (RAS) with plant production. As such, fish, which receive a diet that is rich in protein daily, produce waste that flows into the hydroponic system. Furthermore, nitrifying bacteria convert ammonia to nitrite, which is then converted to nitrate, which is then used by vegetable crops for growth (Danner et al 2019). Moreover, solid fish waste, which is excreted after digestion, provides many of the macro- and micronutrients that plants need (Bailey & Ferrarezi 2017). Hydroponic systems in this regard depend greatly on continual nutrient supplementation to overcome any inadequacy for crops grown (Love et al 2015). The hydroponic system contributes to nitrification and nutrient uptake by the plants (Bailey & Ferrarezi 2017). This improves the water quality for the fish portion (Yildiz et al 2017), while the aquaculture and hydroponic systems are integrated to minimize water discharge into the atmosphere (Bailey & Ferrarezi 2017).

Farmers prefer growing plants in aquaponic systems because nutrients are regularly delivered as fertilizer for the plants, reducing fertilizer input (Tyson et al 2011). Plant production units in aquaponic systems use hydroponic technology with little nutrient input, allowing aquaponic growers to cultivate a range of vegetable crops to satisfy the needs and preferences of consumers (Short et al 2018). Hydroponic systems use a variety of technologies to provide plant roots with nutrients, including raft or deep-water culture (DWC), nutrient film technique (NFT), and medium-filled beds (MFB) (Resh 2012; Love et al 2015). The use of plant species that are appropriate for hydroponic culture (in aquaponics systems) results in aquaculture waste (Gosh & Choudhary 2019), which is matched to the fish stocking density and nutrients. Greens (spinach, chive, basil, watercress) and lettuce, for example, require a moderate amount of nutrients and are well-suited to aquaponic systems (Mchunu et al 2017). Fruity plants (tomatoes, bell peppers, and cucumbers) require high fish density to provide plants with adequate nutrient levels and require a well-functioning system (Diver 2006; Blidariu & Grozea 2011; Hasan 2014).

Tilapia, aquarium fish, yellow perch, catfish, trout, sea bass, blue gills, koi, carp, goldfish, and freshwater prawns are warm or cold-water fish that are adapted to aquaponics systems (Kopsa 2015). Of these species, tilapia is the most farmed in aquaponics, as well as aquaculture systems, as it can be sold as edible fish, its white flesh, general toughness, rapid growth rate, tolerance to various environmental conditions, rapidity, genetic hardening, and rapid growth (Kopsa 2015; Danner et al 2019) all make it a preferred aquaponic fish. Danner et al (2019) showed that tilapia can tolerate temperature variations of 15-30°C, but between 26-28°C is optimal. However, research stipulates that tilapia can grow well well in temperatures around 23.5°C (Kopsa 2015), which is the range most compatible with vegetable crops considered in an aquaponics system (Somerville et al 2014).

For fish and plants as the components of aquaponics, researchers state that the vegetables and other plants are likely to offer more profit than the fish production in aquaponics system (Baker 2010; Tokunaga et al 2015), with the proportion of 90% profitability obtained from plant production (Somerville et al 2014). There is almost no research of a significant importance on the economics of aquaponics, and those that do exist are largely narrative-based (Skar et al 2015). On this note, Skar et al (2015) pointed out certain flaws in the conclusions, pointing out that they are frequently linked to specialized production systems that develop specific types of fish and plant cultures. This imposes challenges in comparing economic performance among aquaponics systems and detecting windows of opportunity when evaluating fish or horticulture product prices. Similarly, despite numerous discussions of aquaponics' varied symbiotic aspects, the system creates a dependency, increasing the producer's economic risks if one of the two biological systems fails (Skar et al 2015). For these reasons, aquaponics continues to thrive on a smaller scale, with products appealing to tiny, bulk local markets (Skar et al 2015).

According to Bailey & Ferrarezi (2017), farmers should concentrate their production efforts on the most valuable crops or continue to produce a variety of crops to suit market demand, understanding that not all crops are equally profitable. The study also highlighted that the value of crops may change over time and must be carefully assessed before being used as an investment benchmark (Bailey & Ferrarezi 2017). Understanding the values and market prices of the products helps a farmer select the crops that will bring the best returns for the business. Because of the differences in production densities and harvest periods, a similar yield factor per area over time was adopted for this study to give a common framework for comparing results. Market demand for certain products and the possibility that a variety of products will be available from the farmer to the consumer also play a role in crop selection, as such leafy vegetables are considered to be the easiest plants to grow in hydroponics (Bailey & Ferrarezi 2017). Fruit crops have longer production timeframes and generate fewer commercial yields, but leafy vegetables have a quick production time and are in high demand. However, fruit crops worth is frequently more than that of leafy goods (Gosh & Chowdhury 2019).

Climate change can severely affect the ability of small holders to grow enough food for their families (Kom et al 2022). Seasonal crop controls farmers' decisions about planting and cultivating and ultimately the success or failure of the crop (De Beurs & Brown 2013). In some areas, there is a risk of fluctuations during the rainy season and rain patterns during the season. Climate change results in unpredictable rainfall, unpredictable rains, severe storms, and unusually heavy rainfall during and outside the season is interrupted by long dry periods during the rainy season and in many areas during the rainy season (De Beurs & Brown 2013). The effects of these fluctuations are particularly significant for farmers with limited resources. In this regard, agriculture is becoming more vulnerable to heat stress, water scarcity, pests, and diseases that interact with constant pressure on natural resources (De Beurs & Brown 2013).

Agricultural phenology criteria such as the start and end of the growing season, the overall duration of the growing season, and the pace of greening and senescence are critical for crop diversification, crop management, and intensification planning (De Beurs & Brown 2013). The growing times (season), production periods, unit value, and yields are the determinants of the value of a crop (Bailey & Ferrarezi 2017). Choosing high-value crops is one of the strategies to maximize returns in aquaponics systems (Dediu et al 2012). Each crop has a distinct value per unit area, which must be considered when choosing types to grow in order to maximize the farmer's profits (Bailey & Ferrarezi 2017). Thus, long-term data derived from statistics on the fresh produce market, for instance, market value or prices of products, could be used to provide necessary analysis and documentation to plan effective adaptation strategies. Availability of data can also provide some understanding of the effect of variability in peak timing of the growing season. Hence, this paper focuses on the systematic review of vegetable species that are possible in aquaponics in South Africa, to analyze data of six years of average monthly market prices and link these to growing times to provide mechanisms for producers to maximize their return on investment (ROI).

Material and Method. The research steps by Wirza & Nazir (2020) were adopted to conduct the proposed research. The steps in conducted involve the selection of suitable keywords for the process of search, criteria for exclusion and inclusion, quality assessment of the papers, and the analysis of the data extracted from the selected papers. As a first step, a literature survey was conducted on the ISI Web of Knowledge, Web of Science and Scopus using aquaponics and tilapia as keywords. Based on the nature of this research, the keywords: aquaponics, market prices, trend, vegetables, return on investment, South Africa, and combination of the keywords, were defined, and adopted by the author. Different keyword combinations were then used as an attempt to identify research focal areas. Because the number of hits was not particularly large, all articles were individually screened. The process was repeated with the Science Direct and EBSCO database. All papers were individually screened and only articles that met the criteria for the inclusion and exclusion of the identified papers in the search process (Table 1) were considered. A total of 109 articles were included in the literature review (Figure 1).

Table 1

Inclusion and exclusion criteria of the identified studies

Inclusion process	*Exclusion process*
The paper published in the years ranging from 2000 to 2020;	The papers before January 2000;
Published papers and available online;	Published but without source;
Paper consisting of aspects that provide satisfactory details for economic analysis from the market forces of demand and supply, general issues concerning the economic development of aquaponics components;	Articles that comprise of biological themes related to agriculture, and technical aspects in terms of disease;
Methodologies in economics regarding analysis regarding profitability, productivity, price premiums, competitiveness, and others;	Non-economic methodologies concerning biology, geophysics, chemistry, geography, and others;
Articles presented in the English language;	Written other than in the English language;
Of the appropriate duplicate studies, only select the prime studies;	
Relevant grey literature (mainly scientific reports, from research programmes at international and national levels), conference proceedings, peer-reviewed literature;	
The papers selected should provide sound knowledge from the research questions established;	Provides no information for the research questions selected.
World, regional and country specific.	

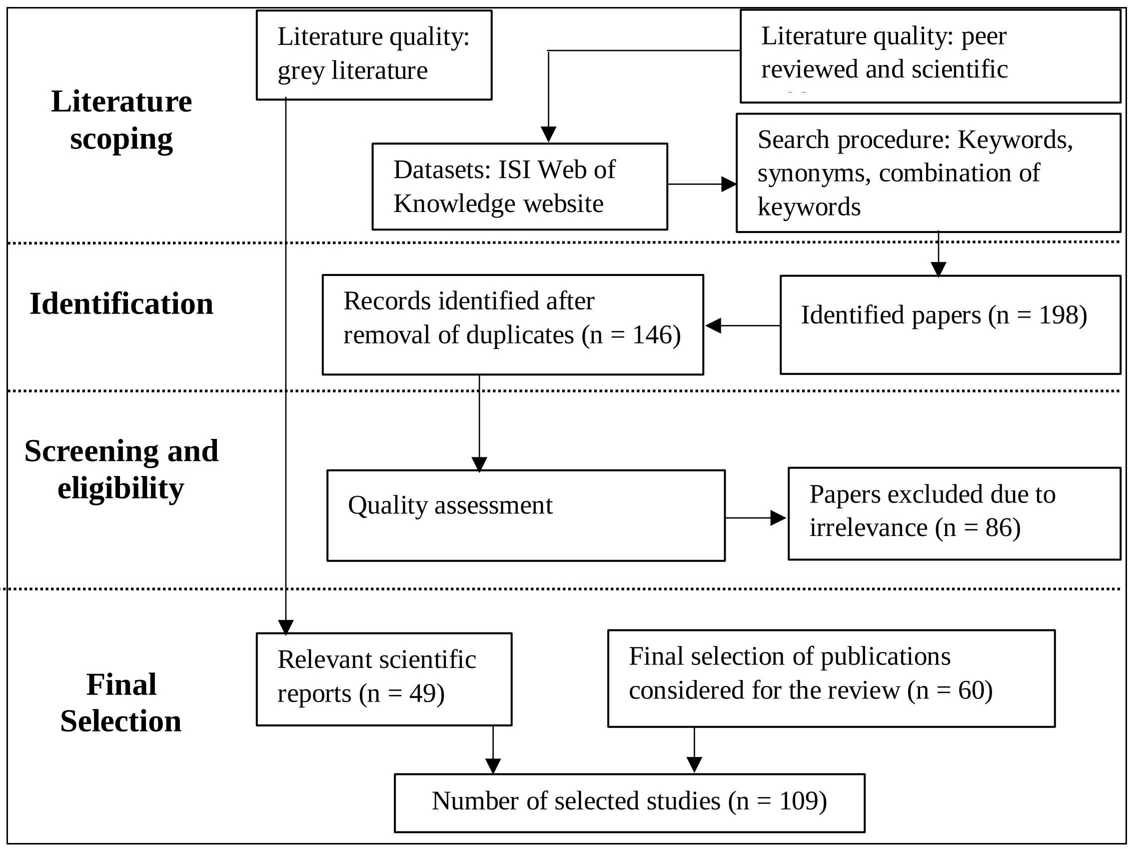


Figure 1. Process of the protocol for conducting the research (Gambelli et al 2019).

The average monthly price trends of vegetable products that were identified to be grown in tilapia aquaponics systems were collected over six years (2015 to 2020). The data on sixteen vegetables (basil (*Ocimum basilicum*), cauliflower (*Brassica oleracea*), lettuce (*Lactuca sativa*), cucumber (*Cucumis sativus*), eggplant (*Solanum melongena*), pepper (*Capsicum annuum*), tomato (*Solanum lycopersicum*), peas (*Pisum sativum*), beans (*Phaseolus vulgaris*), cabbage (*Brassica oleracea* var. *capitate*), broccoli (*Brassica oleracea* var. *italic*), beetroot (*Beta vulgaris*), parsley (*Petroselinum crispum*), carrots (*Daucus carota* subsp. *sativus*), celery (*Apium graveolens*), spinach (*Spinacia oleracea*)) that are common in aquaponics were extracted from a continuously updated database comprised of vegetable prices from 19 fresh produce markets in South Africa. The data were collected and compiled by the Directorate of statistics and economic analysis of the Department of Agriculture, Land Reform and Rural Development (DALRRD) in South Africa. The 2015 to 2020 data were selected as the most recent data accessible from DALRRD. The growing times of each vegetable product were incorporated to produce a mechanism that will assist farmers in maximization of ROI and improve their predictability in market price peak timing. This was to establish when prices of vegetables peak in for the producers to attain the maximum profit upon investment of the production. Furthermore, the average monthly price forecasting for the next six years (2021-2026) was established in this analysis. Moreover, to establish recommendations on the best crops to cultivate, the procedure for the valuation of crops was adopted from Bailey & Ferrarezi (2017).

***Statistical analysis**.* The data was computed using Microsoft excel software to determine the price trend analysis of the vegetable products. Statistical analyses were carried out using SPSS version 25 (SPSS, Chicago, Illinois, USA). All data were subjected to one- and two-way analysis of variance (ANOVA) with the results represented as mean ±SD. Duncan's multiple range test was incorporated to determine the significant differences between the means, with the significant level set at $p < 0.05$. Pearson correlation was conducted to determine the association between price and production average.

***Price forecasting**.* The FORECAST function through Excel 2016 was adopted to calculate a y value for a given x value based on existing x (month and year) and y (average monthly price) values.

Note: For a given value x, FORECAST returns a predicted value based on the linear regression relationship between x values and y values:

y = FORECAST (x, known ys, known xs)

where: x = the x value data point to use to calculate a prediction;

known_ys = the dependent array or range of average monthly prices (y values);

kown_xs = the independent array or range of month vs year (x values).

Results and Discussion. Vegetables are important outputs in improving people's livelihoods by providing a balanced diet and thus improving people's health status, as well as serving as a cash crop in generating income for households (Hagos & Hadush 2016). The commonly used plants in aquaponics are water spinach (*Ipomoea aquatica*) (Endut et al 2011; Effendi et al 2015), spinach (*S. oleracea*) (Shete et al 2013), lettuce (*L. sativa*) (Trang et al 2010; Simeonidou et al 2012; Buzby & Lin 2014; Wahyuningsih et al 2015; Kim et al 2016), beans (*P. vulgaris*) (Estim et al 2019), tomato (*S. lycopersicum*) (Roosta & Hamidpour 2011), cucumber (*C. sativus*) (Savidov et al 2007; Tyson et al 2008; Graber & Junge 2009), pepper (*C. annuum*) (Roosta & Mohsenian 2012), okra (*Abelmoschus esculentus*) (Rakocy et al 2004), chives (*Allium schoenoprasum*) (Savidov et al 2007; Love et al 2015), red amaranth (*Amaranthus cruentus*) (Medina et al 2016), pak-choi (*Brassica rapa*) (Trang et al 2010; Hu et al 2015; Zou et al 2016), basil (*O. basilicum*) (Trang et al 2010), parsley (*P. crispum*) (Savidov et al 2007), and eggplant (*S. melongena*) (Graber & Junge 2009). Many researchers demonstrated that leafy greens such as varieties of *L. sativa* and *O. basilicum* offer good yields in aquaponics systems (Rakocy et al 2003; Trang et al 2010; Mchunu et al 2018).

Somerville et al (2014) explicitly demonstrated that *O. basilicum*, *B. oleracea*, *L. sativa*, *C. sativus*, *S. melongena*, *C. annuum*, *S. lycopersicum*, *P. sativum*, *P. vulgaris*, *B. oleracea* var. *capitate*, *B. oleracea* var. *italic*, and *P. crispum* are the 12 most incorporated crops in aquaponics and they are also common in the fresh market produce of South Africa. Besides the abovementioned, we included beetroot (*B. vulgaris*), carrots (*D. carota* subsp. *sativus*), celery (*A. graveolens*), and spinach (*S. oleracea*). Table 2 presents the common vegetables grown in South Africa in aquaponic systems.

Table 2

Common vegetables, production methods and grow media in aquaponics in South Africa

Vegetable	*Methods*	*Grow media*
L. sativa (55%)	Media-filled bed (MFB) (96%)	Gravel (68%)
D. carota (9%)	Nutrient film technique (NFT) (16%)	Grow stones (18%)
Herbs (46%)	Deep water culture (DWC) (14%)	Peat (2%)
O. basilicum (50%)		
C. annuum (32%)		
C. sativus (25%)		
Ornamental plants (18%)		
S. lycopersicum (16%)		
P. vulgaris and *P. sativum* (16%)		
Cut flowers (7%)		

*Source: Mchunu et al (2018).

On a global perspective, many edible vegetable products have been successfully tested in aquaponics with tilapia (Table 3).

Table 3

Vegetable products tested in aquaponic systems with tilapia species

Tilapia variety	*Plantname*	*Scientific name*	*Crop*	*Reference*
Tilapia	Broccoli	*B. oleracea*	Head vegetable	Nadia et al (2019)
Tilapia	Beetroot	*B. vulgaris*	Root vegetable	Akter et al (2020)
Tilapia	Lettuce	*L. sativa*	Leafy vegetable	Rakocy (2002)
Tilapia	Lettuce	*L. sativa*	Leaf vegetable	Baker (2010)
Tilapia	Lettuce	*L. sativa*	Leaf vegetable	Tokunaga et al (2015)
Nile tilapia	Lettuce	*L. sativa*	Leaf vegetable	Delaide et al (2017)
Nile tilapia	Lettuce	*L. sativa*	Leaf vegetable	Sace & Fitzsimmons (2013)
Gift tilapia	Lettuce	*L. sativa*	Leaf vegetable	Geisenhoff et al (2016)
Nile tilapia	Lettuce varieties	*L. sativa*	Leaf vegetable	Pinho et al (2017)
Nile tilapia	Basil	*O. basilicum*	Herb	Delaide et al (2017)
Nile tilapia or red tilapia	Basil	*O. basilicum* 'Genovese	Herb	Rakocy et al (2004)
Nile tilapia	Basil	*O. basilicum* 'Genovese	Leaf vegetable	Bailey & Ferrarezi (2017)
Nile tilapia	Chinese cabbage	*B. rapa pekinensis*	Leaf vegetable	Sace & Fitzsimmons (2013); Estim et al (2019)
Nile tilapia	Green beans	*P. vulgaris*	Fruit vegetable	Estim et al (2019); Saufie et al (2020)
Nile tilapia	Pac choi	*B. rapa*	Leaf vegetable	Sace & Fitzsimmons (2013)
Nile tilapia	Pac choi	*B. rapa*	Leaf vegetable	Bailey & Ferrarezi (2017)
Nile tilapia	Kale	*B. oleracea*	Leaf vegetable	Bailey & Ferrarezi (2017)
Nile tilapia	Collards	*B. oleracea*	Leaf vegetable	Bailey & Ferrarezi (2017)
Nile tilapia	Swiss chard	*B. vulgaris*	Leaf vegetable	Bailey & Ferrarezi (2017)

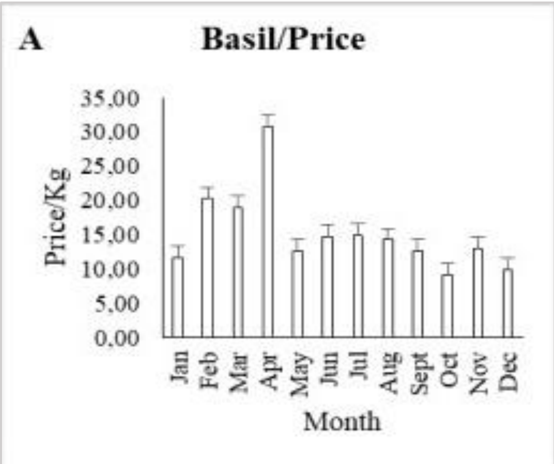
Apart from tilapia, other fish species have been integrated into aquaponics and have become popular, for instance, rainbow trout (*Oncorhyncus mykiss*) and brown trout (*Salmo trutta*). Trout demonstrated good outcomes in aquaponics, and it is thought to thrive better in aquaponics culture conditions than tilapia as it can be reared at a lower temperature of less than 17°C (Thorarinsdottir et al 2015). However, they do require a large biofilter and more aeration (Thorarinsdottir et al 2015). Mchunu et al (2018) agree with the notion that tilapia is the most raised fish in aquaponics in South Africa. Following the national survey on aquaponics, the commonly adopted fish species in aquaponics in South African include tilapia (82%) and trout (30%), with a lower occurrence of barbel/catfish (18%), ornamental fish (16%), and bass and bluegill (both 2%) (Mchunu et al 2018).

Of the sixteen vegetable that are presented in this study, the following showed non-significant results: *L. sativa* (ANOVA, F (11, 60) = 1.36, p = 0.57), *C. annuum* (ANOVA, F (11, 60) = 1.94, p = 0.203), *S. lycopersicum* (ANOVA, F (11, 60) = 2.28, p = 0.182), *P. sativum* (ANOVA, F (11, 60) = 2.26, p = 0.894), *P. vulgaris* (ANOVA, F (11, 60) = 2.58, p = 0.689), *B. oleracea* var. *capitate* F (11, 60) = 2.03, p = 0.945, *B. oleracea* var. *italic* (ANOVA, F(11, 60) = 1.92, p = 0.07), *D. carota* subsp. *sativus* (ANOVA, F (11, 60) = 0.81, p = 0.80). The below vegetables showed significant results.

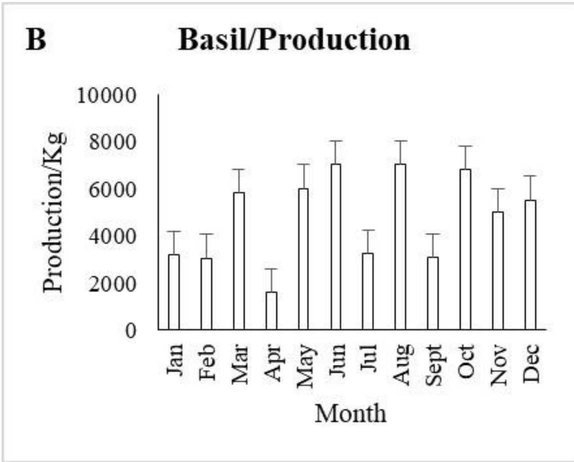
Basil. Basil (*O. basilicum*) is one of the most popular herbs to grow in aquaponics units, especially in large-scale commercial monoculture units due to its high demand and high value in urban or peri-urban areas (Somerville et al 2014). Many cultivars of *O. basilicum* have been tried and tested in aquaponic units including the Italian Genovese basil (sweet basil), lemon basil, and purple passion basil (Trang et al 2010), and *O. basilicum* requires 5-6 weeks of grow-out to market size (Somerville et al 2014). Ferrarezi & Bailey (2019) pronounced that *O. basilicum* has potential as a specialty, short-season, and high-value crop in the University of the Virgin Islands (UVI) commercial aquaponics system. Ferrarezi & Bailey (2019) also recommend the growing of *O. basilicum* from late November to February. Average monthly market prices of *O. basilicum* were highly significant, F (11, 60) = 0.86, p < 0.0001, with price of *O. basilicum* being significantly higher in April (R30.68±35.78/kg) compared to January (R11.57±4.49/kg), May (R12.5±8.51/kg), September (R12.5±4.76/kg), October (R9.06 ±4.53/kg) and December (R9.79±6.01/kg) (Figure 2A). A Pearson correlation indicated a strong negative association (r = -0.49, p < 0.0001) between the price and production of *O. basilicum* (Figure 2C). The observed significant correlation may suggest that higher market prices demonstrated in April were engineered by the possible relatively short production outputs, as justified by World Bank Group (2021). As such, the data may articulate that producers could obtain higher profits by timing harvesting during April.

According to Somerville et al (2014), aquaponics growth requirements of *O. basilicum* are:

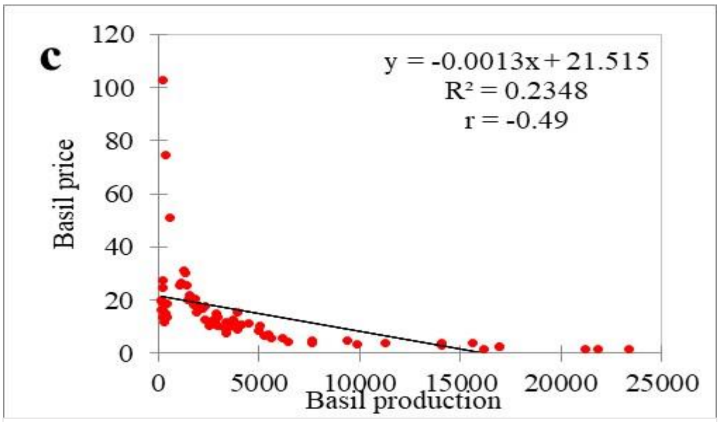
- pH: 5.5-6.5;
- plant spacing: 15-25 cm (8-40 plants m^{-2});
- germination time and temperature: 6-7 days with temperatures at 20-25°C;
- growth time: 5-6 weeks (start harvesting when plant is 15 cm) and continue for 30-50 days;
- temperature: 18-30°C, optimal 20-25°C;
- light exposure: sunny or slightly shaded 20%;
- plant height and width: 30-70 cm and 30 cm respectively;
- recommended aquaponic method: media beds, NFT and DWC.



Average monthly market prices (kg) of basil.



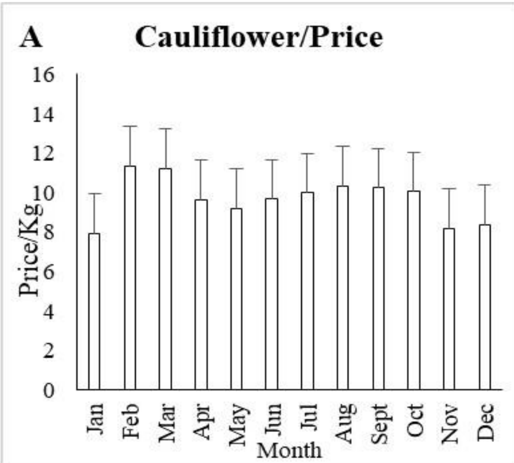
Average monthly production (kg) of basil.



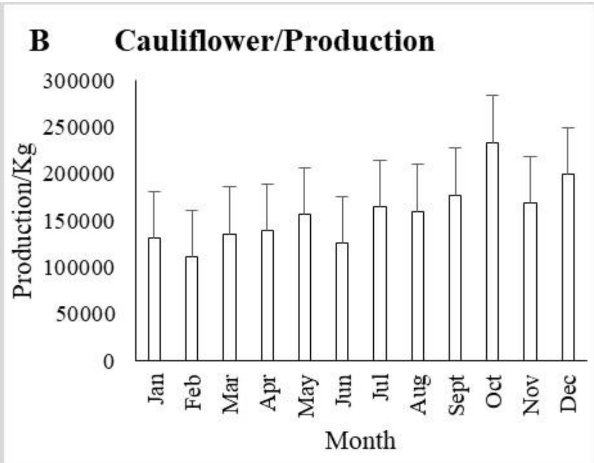
Correlation of average monthly price and production of basil.

Figure 2. Data source: DALRRD (2015 to 2020). Average monthly prices per kilogram (A), average monthly productions per kilogram (B) and the correlation of price and production (C) for basil. Note: Data are mean values of 12 months covering six years period (2015 to 2020) expressed as mean±SD, F(df, error df) = F-Ratio, p = sig. between prices and productions in different months, and r (correlation) and p (significance level) for correlation significance, with the level of the significant set at p = 0.5.

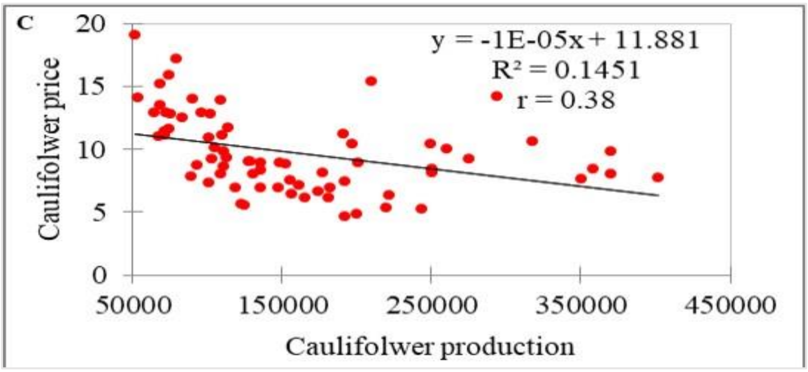
Cauliflower. Cauliflower (*B. oleracea*) is a very valuable and natural crop for winter growth and if enough space is provided, the crop will thrive (Somerville et al 2014). Their development is hampered when exposed to hot or very dry weather conditions (Pang et al 2015). In the economic perspective, the value of cauliflower is suppressed when their heads exhibit cracks, and when insects confront them (Pang et al 2015). *B. oleracea* belongs to the family of Cruciferae vegetable crops that play a significant role in the perspective of economic, nutritional, and potential anticancer value to humankind (Pang et al 2015). Within this Cruciferae family, *B. oleracea* comparatively thrives best in a cool moist climate and it does not tolerate extremely low or high temperatures relative to cabbage (Hossain et al 2014; Ray & Mishra 2017). According to Ray & Mishra (2017) and Schiller (2022), the ideal time to plant most *B. oleracea* cultivars is in the spring (November), so that they grow and produce before summer's heat temperatures ramp up. However, depending on the cultivar, *B. oleracea* can be planted throughout the year (Starke Ayres 2019a). Specific cultivars have been bred for winter, summer, autumn and spring production as well as cultivars that have the ability in certain areas to be grown throughout the year (Ray & Mishra 2017; Starke Ayres 2019a). Thus, in most of South Africa, farmers should avoid planting between May and mid-August as a rule because of the winter cold (Schiller 2022). This makes planting time an especially important factor for *B. oleracea* production to achieve better returns (Ara et al 2009). The production timeline for *B. oleracea* should last for 9 to 17 weeks for it to reach market size. The analysis on the average monthly prices of *B. oleracea* throughout 2015 to 2020 showed highly significant results (ANOVA, F (11, 60) = 0.73, p = 0.001) (Figure 3A). This is articulated by the higher statistical values pronounced in February (R11.35±4.13/kg) and March (R11.22±2.75/kg) than January (R7.92±3.15/kg) (ANOVA, F (11, 60) = 0.73, p = 0.001) (Figure 3A). The highly significant negative correlation was detected through Pearson correlation with the regression value of -0.38, p = 0.001. In the perspective of market forces, this may imply that the demand for *B. oleracea* was higher than the supply during February and March of 2015 to 2020 (Figure 3B). Hence, the rise in prices observed in February and March is likely to be driven by supply shortfalls and strong demand of the short supply of the last month (Liu & Ma 2015; World Bank Group 2021). These data suggest that producers could leverage on the derivable maximum returns during February and March.



Average monthly prices (kg) of cauliflower.



Average monthly production (kg) of cauliflower.



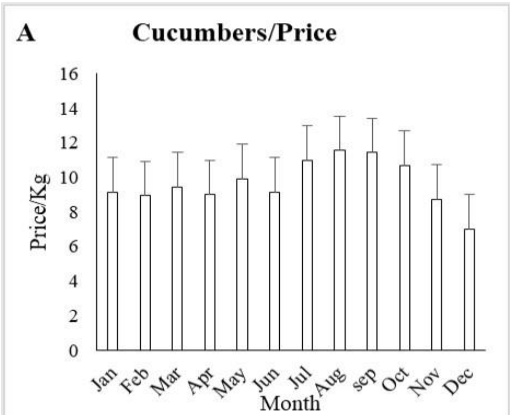
Correlation of average monthly price and production of cauliflower.

Figure 3. Data source: DALRRD (2015 to 2020). Average monthly prices per kilogram (A), average monthly productions per kilogram (B) and the correlation of price and production (C) for cauliflower. Note: Data are mean values of 12 months covering six years period (2015 to 2020) expressed as mean±SD. Legends are the same as Figure 2.

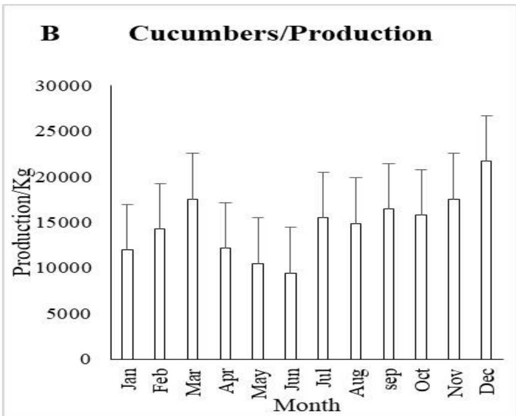
According to Somerville et al (2014), aquaponics growth requirements of *B. oleracea* are:

- pH: 6.0-6.5;
- plant spacing: 45-60 cm (3-5 plants m^{-2});
- germination time and temperature: 4-7 days with temperature 8-20°C;
- growth time: 2-3 months (spring crops), 3-4 months (autumn crops);
- temperature: 20-25°C for initial vegetative growth, 10-15°C for head setting (autumn crop);
- light exposure: full sun;
- plant height and width: 40-60 cm; 60-70 cm respectively;
- recommended aquaponic method: media beds.

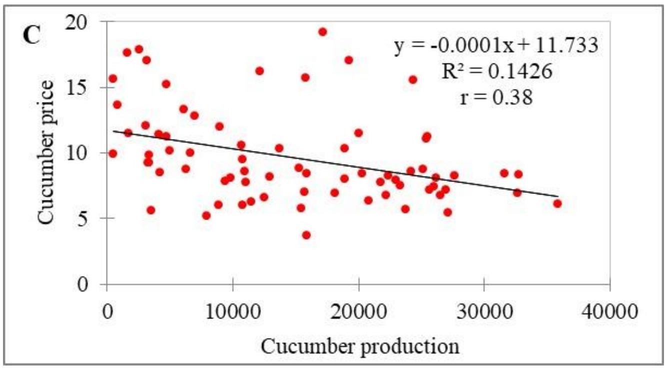
Cucumber. Cucumbers (*C. sativus*) grow up to 2 m annually and are a widespread plant in the Cucurbitaceae family (Mariod et al 2017). There are three main products for cucumber: sliced, pickled, and pitted, resulting in several different varieties within these products (Mariod et al 2017). They are ideal plants to grow in media bed units as they have a large root structure (Somerville et al 2014). Of the Cucurbitaceae family, cucumber is the most significant on a commercial level worldwide (Phuoc 2019). The growth period of *C. sativus* is estimated at 8-10 weeks, but once transplanted, *C. sativus* can start to grow from 2-3 weeks (Somerville et al 2014). Under optimal conditions, plants can be harvested 10-15 times (Somerville et al 2014). According to planting periods established by Starke Ayres (2019d), cucumber could be compatible with the spring and summer months. The current data demonstrated that the monthly market prices of *C. sativus* (Figure 4A) peaked significantly at R11.55±4.05/kg in August and R11.42±4.67/kg in September, compared to December with R7.02±1.88/kg (ANOVA, $F_{(11, 60)} = 0.82$, $p = 0.001$). Additionally, the Pearson correlation illustrated a highly significant negative correlation between price and production ($r = -0.38$, $p = 0.001$: Figure 4C). This interplay may articulate that the fluctuations in the average prices from month to month were greatly influenced by non-static production volumes (Figure 4C), wherein the higher prices observed might have sparked by the dwindling supply of *C. sativus*. Moreover, these data imply that producers could notice the profitability of this vegetable species during August and September.



Average monthly prices (kg) of cucumber.



Average monthly production (kg) of cucumber.



Correlation of average monthly price and production of cucumber.

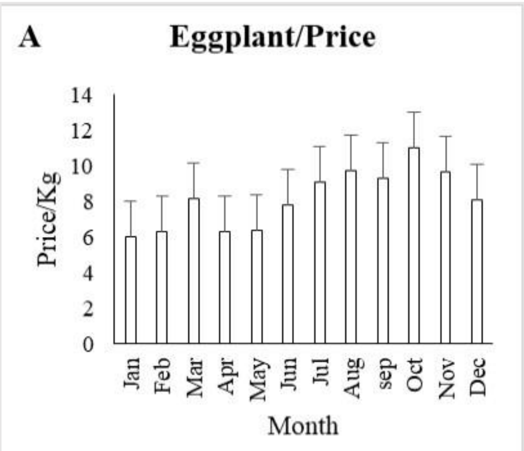
Figure 4. Data source: DALRRD (2015 to 2020). Average monthly prices per kilogram (A), average monthly productions per kilogram (B) and the correlation of price and production (C) for cucumber. Note: Data are mean values of 12 months covering six years period (2015 to 2020) expressed as mean±SD. Legends are the same as Figure 2.

According to Somerville et al (2014), aquaponics growth requirements of *C. sativus* are:

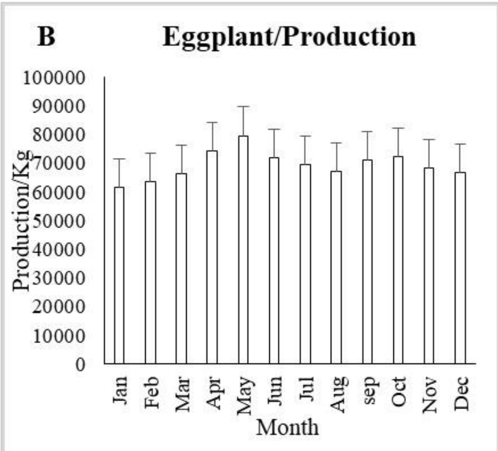
- pH: 5.5-6.5;
- plant spacing: 30-60 cm (depending on variety; 2-5 plants m^{-2});
- germination time and temperature: 3-7 days; 20-30°C;

- growth time: 55-65 days;
- temperature: 22-28°C day, 18-20°C night; highly susceptible to frost;
- light exposure: full sun;
- plant height and width: 20-200 cm; 20-80 cm respectively;
- recommended aquaponic method: media beds; DWC.

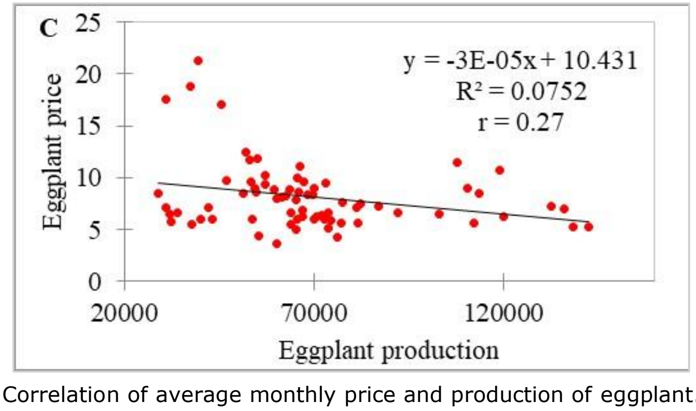
Eggplant. Eggplant (*S. melongena*) is another fruitful summer vegetable that grows well in aquaponics, especially in growing beds and pipes (Somerville et al 2014). *S. melongena* enjoys warm to very warm temperatures with full sun exposure but is a great source of nutrition with high nitrogen and potassium requirements (Somerville et al 2014). The growth period for *S. melongena* to reach market size is 12-17 weeks and plants can produce 10-15 fruits for a total yield of 3-7 kg (Somerville et al 2014). *S. melongena* is overly frost-sensitive and cannot withstand winter conditions (Somerville et al 2014; Burrows 2023). Based on the establishments by Starke Ayres (2019c), the production of *S. melongena* can be scheduled for February to May in Lowveld (frost-free areas), September to December in Middleveld (moderate areas), October to November in Highveld (cold areas), and October to December in the Western Cape. The average monthly market prices analysis was highly significant, F (11, 60), = 1.69, p = 0.02, with the price of peaked significantly higher in October (R11±5.62/kg) in comparison with R6.02±0.58/kg in January (Figure 5A). Negative correlation between price and production was evident with r = -0.27, p = 0.02 through Pearson correlation (Figure 5C). Thus, the observed substantial rise in the cost of *S. melongena* may have triggered by the escalated logistics costs and production inputs cost (pesticides, fertilizers, and other agricultural products) (Liu & Ma 2015). However, producers could maximize their profits during October with reference to the current data.



Average monthly price (kg) of eggplant.



Average monthly production (kg) of eggplant.



Correlation of average monthly price and production of eggplant.

Figure 5. Data source: DALRRD (2015 to 2020). Average monthly prices per kilogram (A), average monthly productions per kilogram (B) and the correlation of price and production (C) for eggplant. Note: Data are mean values of 12 months covering 6 years period (2015 to 2020) expressed as mean±SD. Legends are the same as Figure 2.

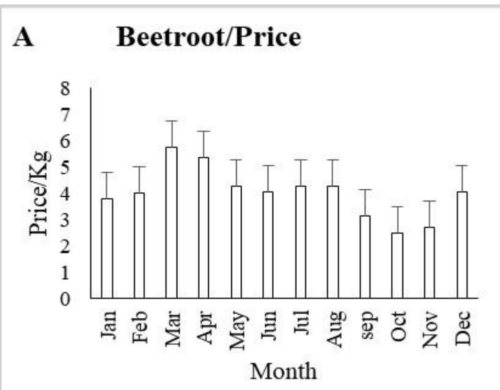
According to Somerville et al (2014), aquaponics growth requirements of *S. melongena* are:

- pH: 5.5-7.0;
- plant spacing: 40-60 cm (3-5 plants m^{-2});
- germination time and temperature: 8-10 days; 25-30°C;
- growth time: 90-120 days;
- temperature: 15-18°C night, 22-26°C day; highly susceptible to frost;
- light exposure: full sun;
- plant height and width: 60-120 cm; 60-80 cm respectively;
- recommended aquaponic method: media beds.

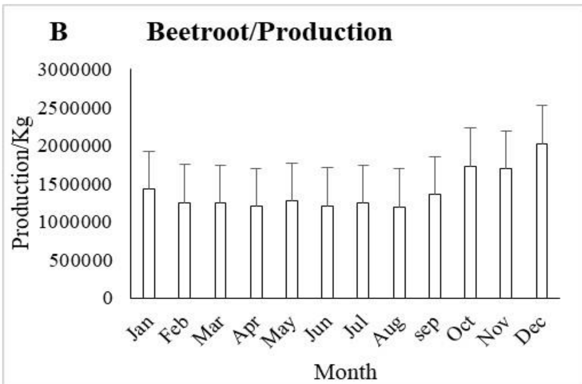
Beetroot. Beetroot (*B. vulgaris*) is commonly called garden beet, and traditionally, is eaten as a food and has a high nutritional value (Ninfali & Angelino 2013). It is now being recognized as a functional food (Ninfali & Angelino 2013). Akter et al (2020) successfully tested *B. vulgaris* through the media bed method of production in aquaponics. The growing timeline to maturity for this crop lasts for 10-14 weeks (Reddy 2020a). *B. vulgaris* is generally a widely adaptable crop that can be grown under most conditions throughout South Africa (Starke Ayres 2019b). This vegetable species can be planted all year round (similar to broccoli) but as a rule of thumb, areas where there could be frost conditions around planting time or the possibility of scorching from excessive heat, should be avoided (Starke Ayres 2019b). Likewise, with broccoli, *B. vulgaris* is a cool-weather crop that can grow annually (Starke Ayres 2019b, d; ARC 2013a, b). The species can be planted during spring, summer, and autumn (Starke Ayres 2019b, d; ARC 2013a, b). The current data showed that the main effect of the month in average price was highly significant, ANOVA, F (11, 60) = 2.04, p < 0.0001, whereby March (R5.75±2.08/kg) reported a significantly higher average market price than September (R3.15±0.6/kg), October (R2.48± 0.68/kg), and November (R2.7±0.9/kg), respectively (Figure 6A). This may imply that producers could gain better returns around March out of the investments in the production of *B. vulgaris.* Price and production average reported a highly significant negative correlation, r = 0.56, p < 0.00001 (Figure 6C). This suggests that the production volumes sparked the fluctuations in the average monthly prices.

According to Reddy (2020a), aquaponics growth requirements of *B. vulgaris* are:

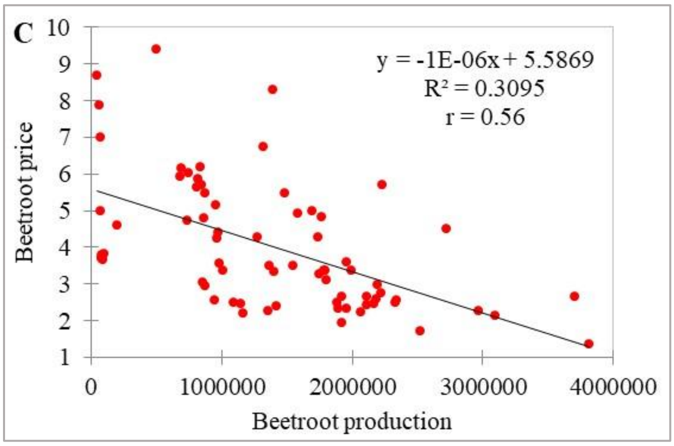
- pH: 6-7;
- plant spacing: 15-20 cm (2-5 plants m^{-2});
- germination time and temperature: 7-14 days; 12-23°C;
- growth time: 70-100 days from transplant;
- temperature: 10-29°C;
- light exposure: full sun;
- plant height and width: 30-46 cm; 46-61 cm respectively;
- recommended aquaponic method: media beds.



Average monthly prices (kg) of beetroot.



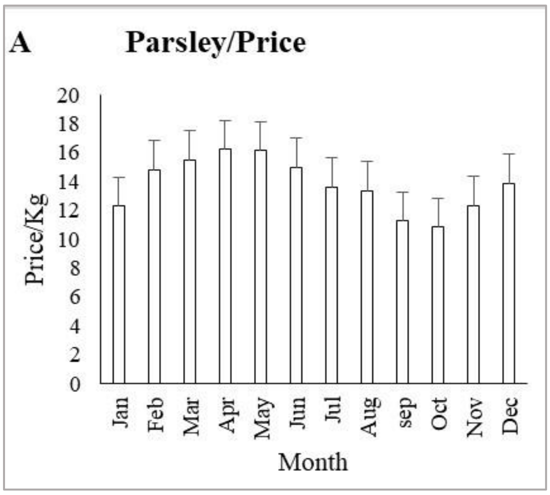
Average monthly production (kg) of beetroot.



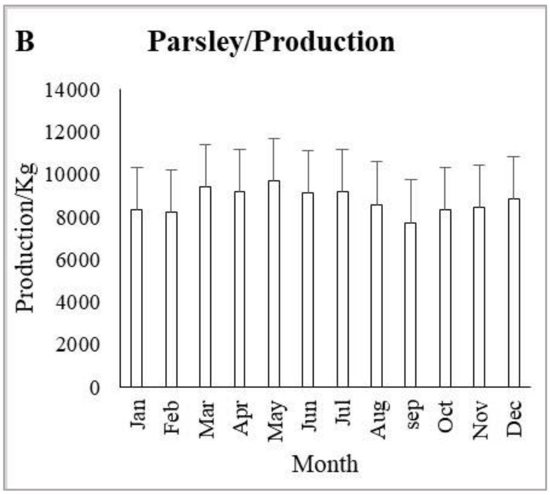
Correlation of average monthly price and production of beetroot.

Figure 6. Data source: DALRRD (2015 to 2020). Average monthly prices per kilogram (A), average monthly productions per kilogram (B) and the correlation of price and production (C) for beetroot. Note: Data are mean values of 12 months covering 6 years period (2015 to 2020) expressed as mean±SD. Legends are the same as Figure 2.

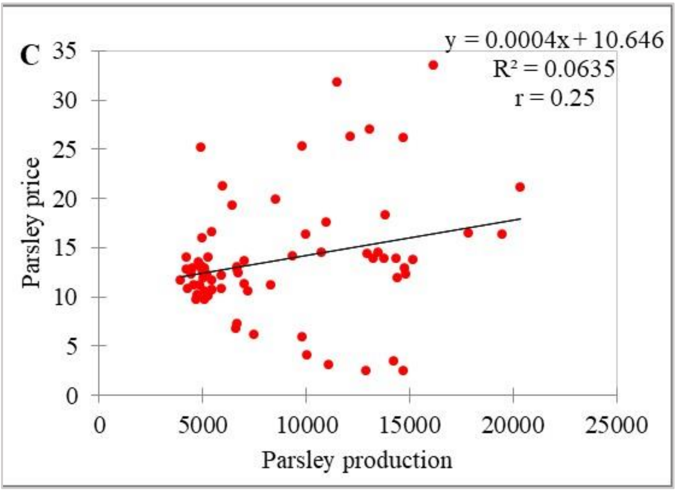
Parsley. Parsley (*P. crispum*) is a common herb plant grown in domestic and commercial aquaponic units due to its nutritional content (rich in vitamins A and C, calcium and iron) and high market value (Somerville et al 2014). *P. crispum* herbs are easy to grow because their nutrient requirements are low compared to other vegetable crops (Somerville et al 2014). Roosta (2014) successfully tested *P. crispum* in aquaponics. This vegetable species is a biennial herb grown throughout the year (Starke Ayres 2019d). However, Spiro (2016) recommends the growing of parsley during the spring months. The planting time of *P. crispum* may stretch up to five weeks (Starke Ayres 2019d). There was a significant difference between the average monthly prices of *P. crispum*, ANOVA, F (11, 60) = 0.48, p = 0.03, wherein statistical mean values reported higher price peak in April (R16.20±7.26/kg) than October (R10.85±4.8/kg) (Figure 7A). The results on Pearson correlation reported a significant positive relationship (r = 0.25, p = 0.03) between price and production (Figure 7C). This may translate to the production outputs of this vegetable species contributing to the possible maximum return that producers could gain during April.



Average monthly prices (kg) of parsley.



Average monthly production (kg) of parsley.



Correlation of average monthly price and production of parsley.

Figure 7. Data source: DALRRD (2015 to 2020). Average monthly prices per kilogram (A), average monthly productions per kilogram (B) and the correlation of price and production (C) for parsley. Note: Data are mean values of 12 months covering 6 years period (2015 to 2020) expressed as mean±SD. Legends are the same as Figure 2.

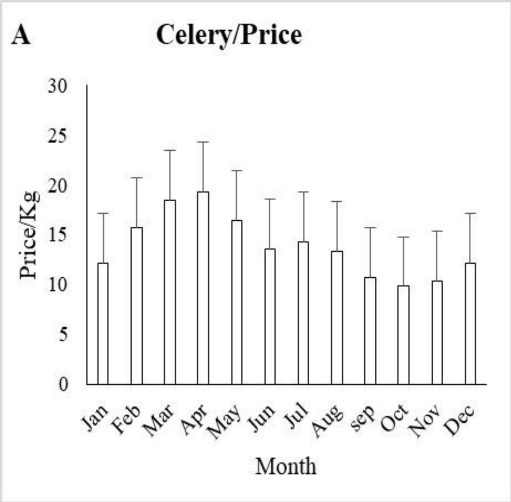
According to Somerville et al (2014), aquaponics growth requirements of *P. crispum* are:

- pH: 6-7;
- plant spacing: 15-30 cm (10-15 plants m^{-2});
- germination time and temperature: 8-10 days; 20-25°C;
- growth time: 20-30 days after transplant;
- temperature: 15-25°C;
- light exposure: full sun, partial shade at > 25°C;
- plant height and width: 30-60 cm; 30-40 cm respectively;
- recommended aquaponic method: media beds, NFT and DWC.

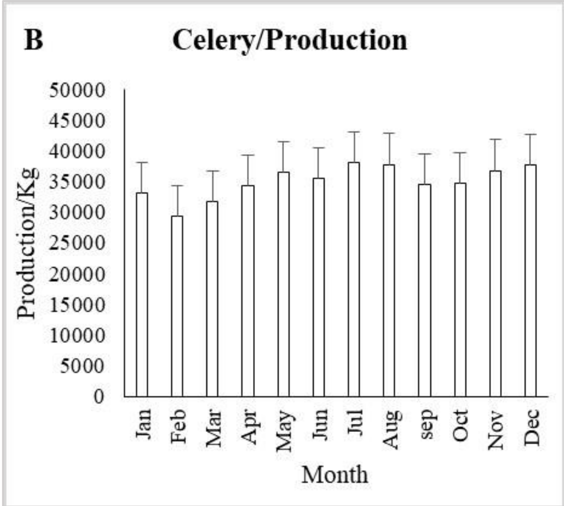
Celery. Celery (*A. graveolens*) is a cool-season herb and vegetable that belongs to the parsley family and is often grown as an annual for fresh consumption in the market (Malhotra 2006; Combs & Ernst 2019). *A. graveolens* require a longer growing season than most vegetables (Combs & Ernst 2019). The growing period could prolong for about 12-17 weeks (Malhotra 2006). According to the "seasonal fruit and vegetable chart for South Africa" by Spiro (2016), planting celery can occur in all seasons of the year, however, Sowing Chart – South Africa (2014) and Brodie (2021) stipulated September to December as the recommended time for growing of *A. graveolens*. Significant differences between the average monthly prices of celery were found (ANOVA, F (11, 60) = 0.81, $p < 0.0001$). The highest prices are in April (R19.28±12.42/kg) in comparison October (R9.8±6.37/kg) (Figure 8A). Price and production reported a strong negative significantly high correlation (Pearson correlation, $r = -0.726$, $p < 0.0001$: Figure 8C). This may reflect that the price in this instance was dependent upon a supply of this vegetable species.

According to Malhotra (2006) and Combs & Ernst (2019), aquaponics growth requirements of *A. graveolens* are:

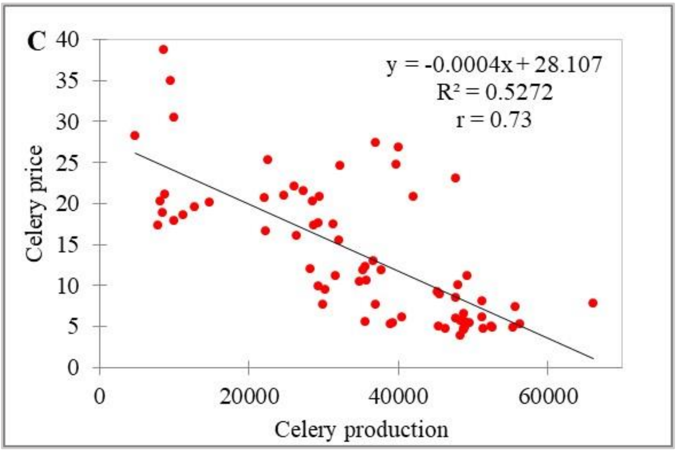
- pH: 6-7;
- plant spacing: 25-30 cm (6 plants m^{-2});
- germination time and temperature: 14-21 days; 21-24°C;
- growth time: 90-120 days after transplant;
- temperature: 16-21°C;
- light exposure: full sun;
- plant height and width: 60-90 cm; 40 cm respectively;
- recommended aquaponic method: DWC, Media bed.



Average monthly prices (kg) of celery.



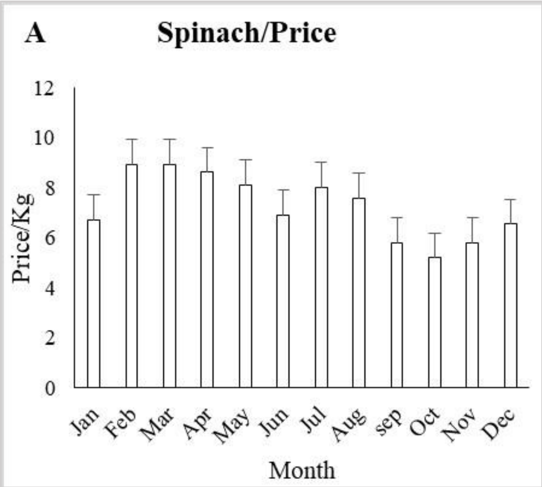
Average monthly production (kg) of celery.



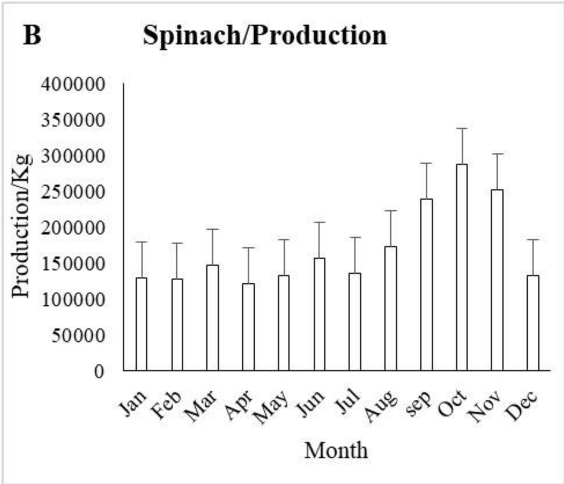
Correlation of average monthly price and production of celery.

Figure 8. Data source: DALRRD (2015 to 2020). Average monthly prices per kilogram (A), average monthly productions per kilogram (B) and the correlation of price and production (C) for celery. Note: Data are mean values of 12 months covering 6 years period (2015 to 2020) expressed as mean±SD. Legends are the same as Figure 2.

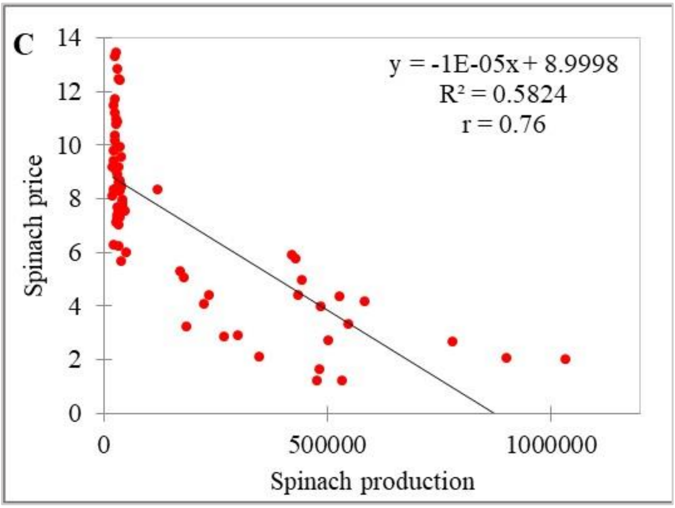
Spinach. Spinach (*S. oleracea*) is a cool-season leafy vegetable that grows rapidly (Seaman 2016). *S. oleracea*, an annual plant with significant yields in a short time, is a green, leafy vegetable that may be cultivated in both spring and autumn (Murcia et al 2020). It is known for its nutritive value and recognized as one of the most popular vegetables in some regions of the world and has shown a perpetual growth in terms of economic importance, particularly fresh-market *S. oleracea* (Chitwood 2016). According to DAFF (2010), the planting of *S. oleracea* in South Africa can be scheduled for August up to April. The grow-out of *S. oleracea* can last for 5-7 weeks (Reddy 2020b). The data showed that there were higher significant differences between marketed average price means (Figure 9A) of *S. oleracea* (ANOVA F (11, 60) = 0.99, $p < 0.0001$), with February (R8.92±3.02/kg) and March (R8.93±3.63/kg) reporting significantly higher prices relative to October (R5.2±2.89/kg). Results of the Pearson correlation pronounced a strong negative association (Figure 9C) between price and production means ($r = 0.76$, $p < 0.0001$). This correlation may indicate that the higher prices observed in February and March could be established by the short supply of this vegetable in the market (Liu & Ma 2015). Besides shortage of supply increased prices could be formulated by the possible escalations in prices of different inputs (for example, seeds), increasing demand and possibly increasing population (Fatima et al 2015). This may entice new suppliers to the market, looking at the possible highest profit gains around this month, which may also impose competition to the old suppliers (Liu & Ma 2015).



Average monthly prices (kg) of spinach.



Average monthly production (kg) of spinach.



Correlation of average monthly price and production of spinach.

Figure 9. Data source: DALRRD (2015 to 2020). Average monthly prices per kilogram (A), average monthly productions per kilogram (B) and the correlation of price and production (C) for spinach. Note: Data are mean values of 12 months covering 6 years period (2015 to 2020) expressed as mean±SD. Legends are the same as Figure 2.

According to Reddy (2020b), aquaponics growth requirements of *S. oleracea* are:

- pH: 6.0-7.0;
- plant spacing: 10-13 cm (30-60 plants m^{-2});
- germination time and temperature: 5-9 days; 18-24°C;
- growth time: 37 to 45 days;
- temperature: 16-18°C;
- light exposure: full sun;
- plant height and width: 15-30 cm; 15-30 cm respectively;
- recommended aquaponic method: DWC, Media bed, NFT.

Average monthly prices (R) and production (kg). It is evident that the average monthly price at market level is volatile in selected vegetables, including *P. sativum*, *B. oleracea* and *O. basilicum* (Figure 10). That of other crops are relatively stable thgroughout. Producers assessing value on the individual price per vegetable crop should select peas to produce, given that it has the highest value in terms of price, followed by broccoli (Figure 10). However, based on the price vs production scenario, it explicitly shows that these high prices of peas are at the expense of low traded produce quantities (Figure 11). Inversely, in terms of production, *S. lycopersicum* depicted consistantly higher output trend throughtout the months (Figure 11). Other vegetable species showed relatively stable monthly trends throughout regarding production (Figure 11).

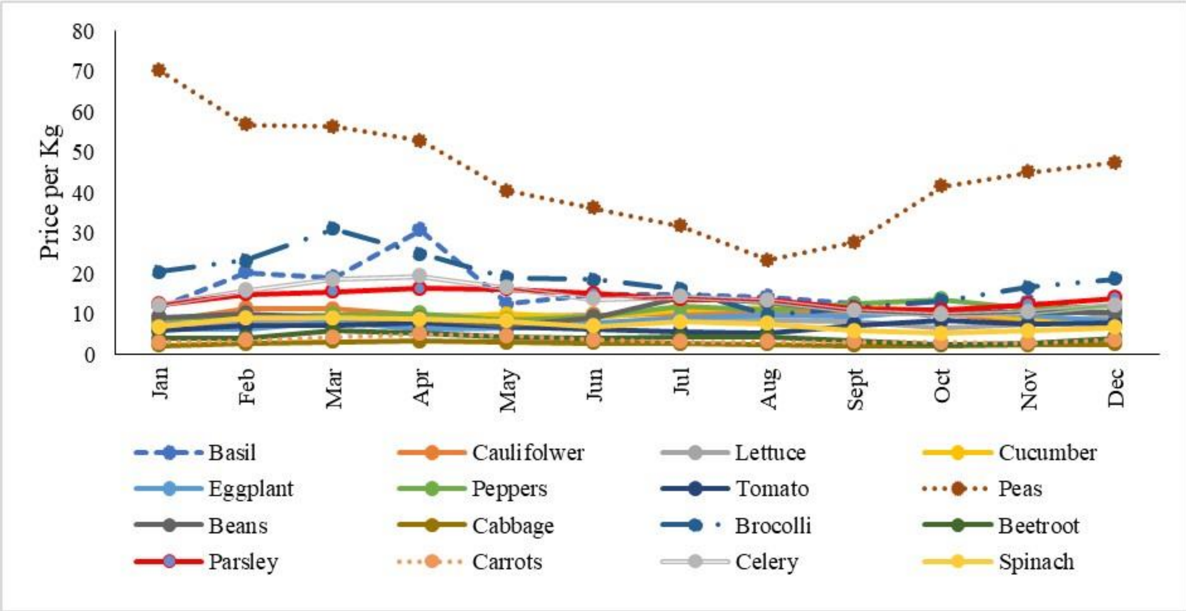


Figure 10. Average monthly prices (kg) over period of 6 years (2015-2020) of basil, cauliflower, lettuce, cucumbers, eggplant, peppers, tomato, peas, beans, cabbage, broccoli, beetroot, parsley, carrots, celery, spinach.

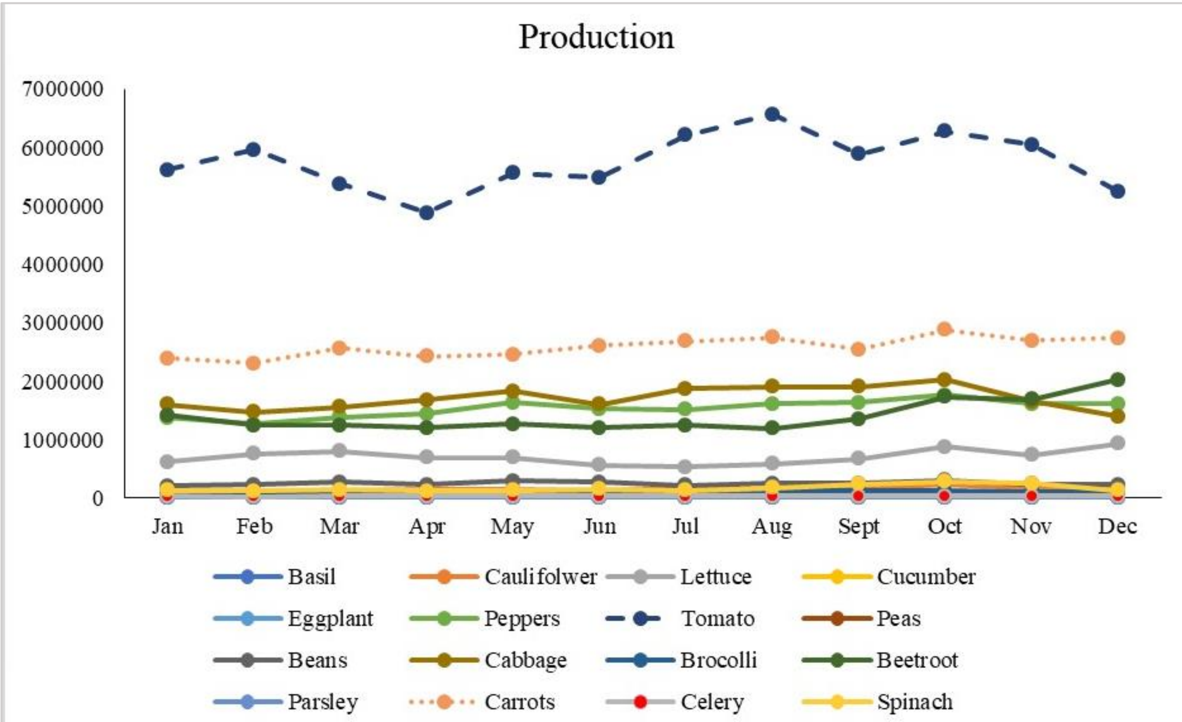


Figure 11. Average monthly productions (kg) of basil, cauliflower, lettuce, cucumbers, eggplant, peppers, tomato, peas, beans, cabbage, broccoli, beetroot, parsley, carrots, celery, spinach over 6 years period 2015 to 2020.

A better indication of price vs volume is an analysis of maximum price kg^{-1} m^{-2} (Figure 12, Annexure 1). Bailey & Ferrarezi (2017) pronounced that the value of each crop is typically influenced by unit value, production timeline, density, and yield. In general, crops yield differently regarding value per unit area, and this should be observed when choosing a variety of crops to produce to give the best returns to the producers (Bailey & Ferrarezi 2017). As such, as *P. sativum* constantly demonstrated a higher monthly price trend over the six years (as mentioned earlier), however, Annexure 1 demonstrated that peas yield in kilogram per plant per square meter (kg plant^{-1} m^{-2}) is relatively lower compared with some other crops, which subsequent to the comparatively lower total value (Figure 12). Despite this, the demonstrated lower yield capacity of *P. sativum* may signify that the product is labour intensive (Silva et al 2019). Hence, it is noticeable on Annexure 1 that *P. sativum* is a comparatively low-yielding commodity, which may be attributed by this increasing market prices consequential from the exertions to balance supply and demand factors (Sherrick 2012). This may have contributed to the relatively lower total value of *P. sativum*, which may signify that producers may obtain lower returns from the production of *P. sativum* (Figure 12).

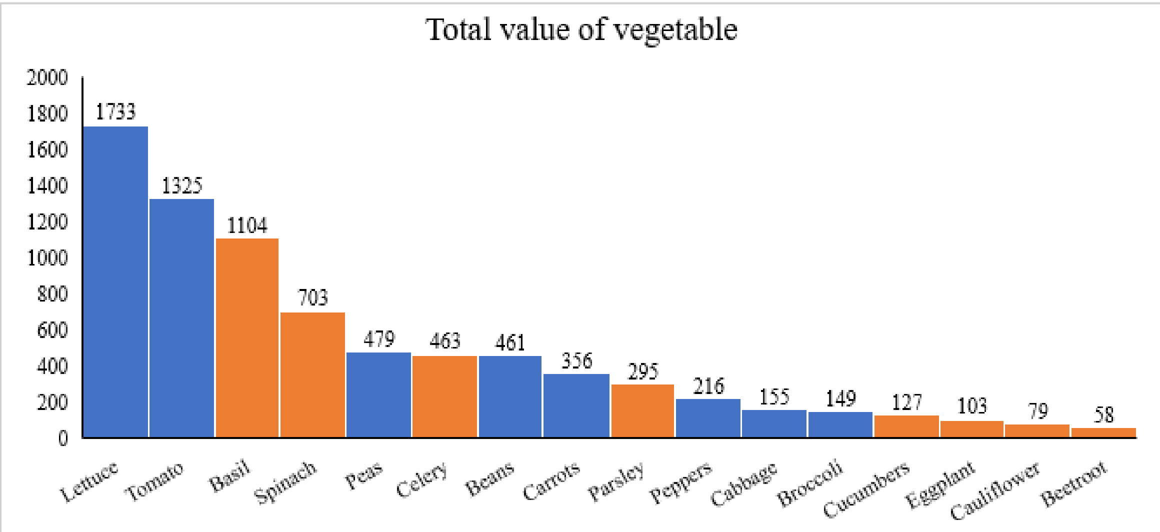


Figure 12. Total value of vegetable products that in terms of price analysis. Yield (kg plant^{-1} m^{-2}) multiplied by maximum price (R kg^{-1}) for each of the represented vegetable products. Note: Vegetable products represented with orange bars are those that showed significant results in terms of average monthly price analysis. The yield for the vegetable products represented were sourced from (Hoffmann & Harrison (2018); Fourie 2010).

Petljak et al (2018) stated that the causative agents of lower prices of the products include higher yields that may reflect the existence of higher suppliers. This view corroborates the current analysis. Based on the analysis presented by Figure 12, *L. sativa* is by far a better crop in term of the total value, as it is also attributed by fast growth, low nutritional requirements and expanding market acceptance (Sala & da Costa 2012), then followed by *S. lycopersicum*, and these two crops demonstrated relatively lower average prices (Annexure 1). This is articulated by the noticeable higher yields (kg plant^{-1} m^{-2}) stipulations characterized by lower maximum market prices (Annexure 1). In contrast to *P. sativum*, the analysis on *L. sativa* and *S. lycopersicum* in this instance may be suggestive of the higher labour force requirements induced by their higher-yielding capacity, as demonstrated by Silva et al (2019). As mentioned earlier, in aquaponics, leafy vegetables (e.g., *L. sativa*) thrive well with the ample amount of nitrogen concentrations, have a relatively short growing period (Table 4), and are in high demand (Bailey & Ferrarezi 2017). Fruiting crops (e.g., *S. lycopersicum*) have a longer growing timeline and offer comparatively less marketable yield, though their value is often higher than that of the leafy products (Bailey & Ferrarezi 2017). As such, the higher yield (kg plant^{-1} m^{-2}), higher total value, short production period, which formulate the ability of a crop to offer good returns, hence this make *L. sativa* a relatively better and highly recommended crop for producers to incorporate in the aquaponics production in order to obtain considerably better returns. *L. sativa* is in this instance followed by *S. lycopersicum* (Annexure 1), however, it should be noted that *S. lycopersicum* takes a longer period to grow to market size. Bailey & Ferrarezi (2017) demonstrated that the planting density and shorter growing period capacitate the higher individual value of this crop, underpin these inferences on *L. sativa*. However, depending on the main subjects of this analysis, with a closer look at the vegetables that showed significant results (Figure 12) in terms of average monthly prices, basil is in this instance showed the capacity to offer greater revenues at a growing time of February to March over a relatively shorter growing period of one to two months. Following basil is spinach, which may be suggested as a better alternative to spinach, this is articulated by the fact that spinach also paraded better profits if it is to be cultivated around December and January over a period of one to two months.

Off the context of this study, the observations regarding the total value (Figure 12), yield (kg plant^{-1} m^{-2}) (Annexure 1), *L. sativa* and *S. lycopersicum* could be considered as better options to attain good returns.

Price forecasting. Vegetables are important to farmers and citizens, and the fluctuation of vegetable prices affects every consumer's wallet, which may cause widespread concern in society (Qu et al 2017). Large increases in staple food consumption prices have a greater negative impact on poor households than on rich households, because the have-nots spend roughly three-quarters of their income on food consumption. Food price fluctuations, particularly for vegetables, may be seasonal and, at times, expected (Groom & Tak 2013). Generally, the forecasted average monthly prices (Figure 13) estimate vegetable price hikes during the next six years period of 2021 to 2026.

Figure 13 projected the ups and downs on the vegetable prices, but somehow smooth. However, dramatic prices increase are projected for basil then celery over other vegetables represented. Higher production cost could be one of the causative agents to this, as it is pronounced by Illankoon & Kumara (2020) that the reasons behind price hikes could be the supply as well as environmental conditions, demand, social, cultural, and political situations, which are amongst the many dynamics of price volatility. Interestingly, some vegetable, for instance, basil and celery, which had pricing peaks around March and April during the period of 2015 to 2020, are forecasted to price peak around September to October. Climate change could exacerbate pricing peaks due to changing precipitation patterns, increased frequency of some extreme events, and rising temperatures (Hagos & Hadush 2016; Mbow et al 2019). The IPCC (2012) report stated that more extreme climatic events are projected to lead to more agrometeorological disasters with associated economic and social loses. Hence, with current and projected climate change (higher temperature, changes in precipitation patterns, flooding and extremes events), achieving adaptation will require technological adoption for the production of vegetables to promote reasonable prices of these vegetables, by applying outstanding adaptive strategies such as aquaponics. As mentioned earlier, other aspects related to the anticipated high price estimates may relate to supply shortage against high demand of vegetable productions. However, the projected high prices due to suggested possible reasons, may to some extent articulate the changing vegetable growing time (Hagos & Hadush 2016; Olabanji et al 2021). In the quest to attain maximum profits, growers should be guided by the notion of when the prices of a particular vegetable could afford maximum revenues.

Table 4

Vegetable production guideline

Vegetable product	*Month of price peak*	*Grow period (months)*	*Summer*			*Autumn*			*Winter*			*Spring*		
			Dec	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sept*	*Oct*	*Nov*
Basil	April	1-2			Blue	Blue								
			Green	Green	Green									Green
Cauliflower	February and March	2-3	Blue	Blue									Blue	Blue
														Green
Cucumbers	August and September	2-3							Blue	Blue				
			Green	Green	Green								Green	Green
Eggplant	October	3-4							Blue	Blue	Blue	Blue		
			Green		Green	Green	Green	Green				Green	Green	Green
Beetroot	March	2-4	Blue	Blue	Blue									
			Green	Green	Green	Green	Green	Green				Green	Green	Green
Parsley	April	1				Blue								
												Green	Green	Green
Celery	April	3-4	Blue	Blue	Blue	Blue								Blue
			Green									Green	Green	Green
Spinach	February and March	1-2	Blue	Blue										
			Green	Green	Green	Green	Green				Green	Green	Green	Green

Blue colour	Planting time for maximum profit
Green colour	Best planting time

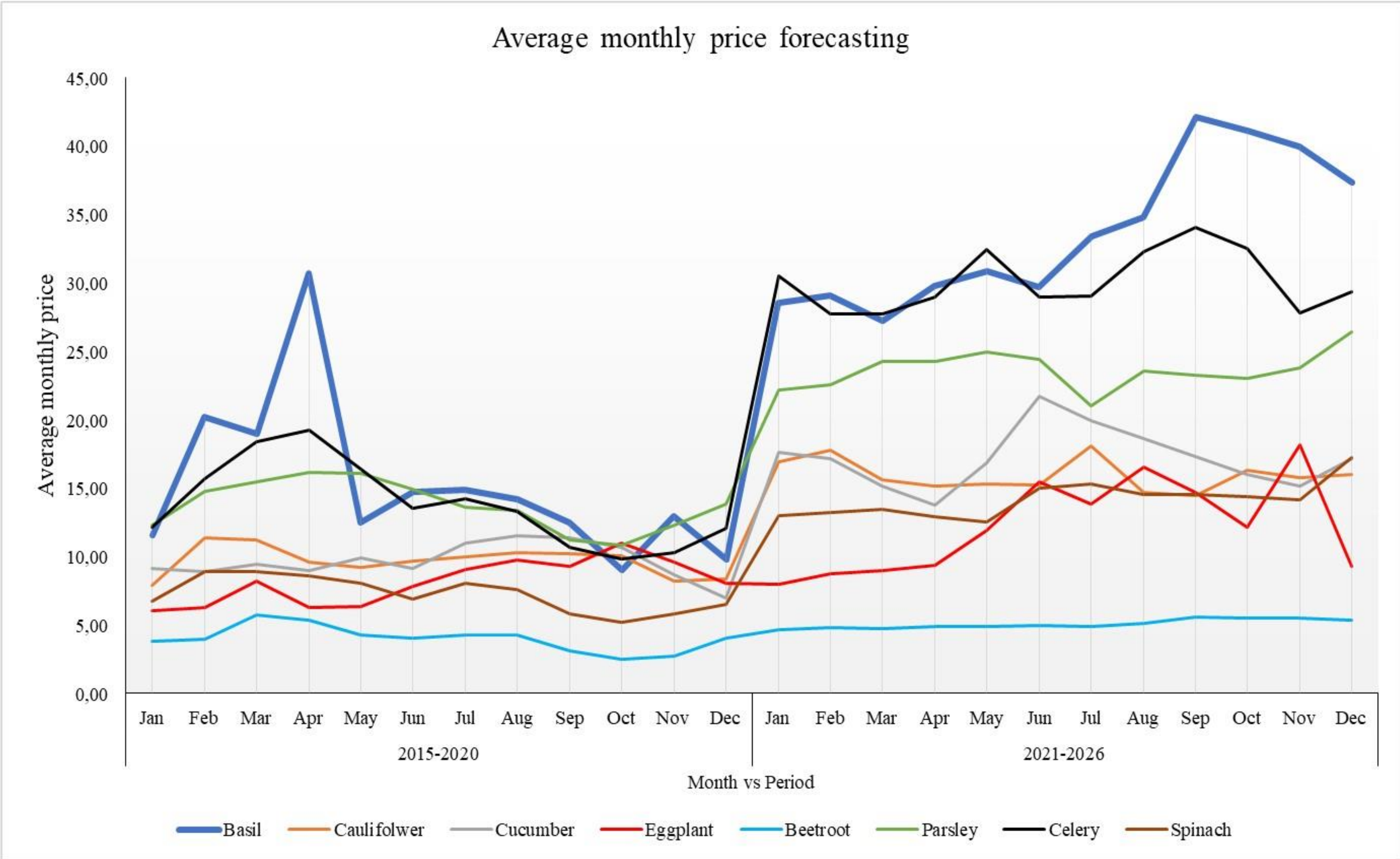


Figure 13. Average monthly price forecasting for the next 6 years (2021-2026) of the eight of sixteen vegetables that showed significant results.

Annexure 1

Average yield, maximum price, and total value of vegetable crops

Product	*Average yield (kg m^{-2})*	*Plant density*	*Yield (kg plant^{-1} m^{-2})*	*Cost*	*Maximum price*	*Total*
Basil	1.50	24	36	338.84	30.68	1104.48
Cauliflower	1.75	4	7	9.01	11.35	79.45
Lettuce	7.75	23	178.25	168.41	9.72	1732.59
Cucumbers	2.75	4	11	14.67	11.55	127.05
Eggplant	4.70	2	9.4	11.37	11	103.40
Peppers	4.00	4	16	29.29	13.53	216.48
Tomato	7	4	160	109.69	8.28	1324.80
Peas	0.90	30	6.80	336.73	70.37	478.52
Beans	1.10	30	33	64.49	13.98	461.34
Cabbage	8	6	48	5.01	3.23	155.04
Broccoli	1.20	4	4.80	46.22	31.03	148.94
Beetroot	2.50	4	10	3.31	5.75	57.50
Parsley	1.40	13	18.20	47.76	16.2	294.84
Carrots	4	18	72	17.64	4.95	356.40
Celery	4	6	24	89.21	19.28	462.72
Spinach	1.75	45	78.75	8.93	8.93	703.23

Conclusions. Vegetable crops are very important due to their higher yield potential, higher return, and high nutritional value, and suitability for small land holding farmers. The prefatory conclusion based on the current analysis is that we can get a better understanding of where data could aid in the local market prices. For instance, prices may be driven by different variables in South Africa. If we combine knowledge of the relationship between planting times and prices, we may be able to improve predictability at the peak of profits. As such, data availability may be most effective in predicting local prices in poorly integrated markets. All of the vegetables represented in the current study are possible in tilapia aquaponics production were proven edible. However, it is of paramount importance for producers to consider investing on the production of vegetable crops that are most valuable or those varieties of crops capacitated in meeting market demand, knowing that each does not contribute equally to cost-effectiveness. The analysis of this paper suggested that basal could be a relatively better crop to incorporate in aquaponics production to attain maximum returns, followed by spinach. It has demonstrated that basil could afford comparatively higher returns on investment at a relatively shorter growing period, and this could be possible if the production period could be targeted around February to March (growing time) over a period of one to two months (production period). On this basis, spinach could serve as a better alternative for basil as it also showed relatively greater returns possible at a growing time around December to January and production period of one to two months. Despite the average monthly prices, should consideration be on the total value of vegetables, recommendations would be allotted to *Lactuca sativa* and *Solanum lycopersicum*, which demonstrated to be of a higher value. This analysis could be of a great assistance to, for instance, extension officer and farmers largely.

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References

Agricultural Research Council (ARC) in South Africa, 2013a Production guideline of winter vegetables. Available at: https://www.arc.agric.za/arc-vopi/Leaflets%20Library/Production%20Guideline%20for%20Winter%20Vegetables.pdf. Accessed: January, 2021.

Agricultural Research Council (ARC) in South Africa, 2013b Production guideline of summer vegetables. Available at: https://www.arc.agric.za/arc-vopi/Leaflets%20Library/Production%20Guideline%20for%20Summer%20Vegetables.pdf. Accessed: January, 2021.

Akter S., Bablee A. L., Rana K. M. S., Nigar M., Nadia Z. M., Salam M. A., 2020 Effects of foliar and root application of epsom salt on aquaponics beetroot (*Beta vulgaris*) production in confined condition. Asian Journal of Medical and Biological Research 6(1):56-66.

Ara N., Kaisar M. O., Khalequzzaman K. M., Kohinoor H., Ahamed K. U., 2009 Effect of different dates of planting and lines on the growth, yield and yield contributing characteristics of cauliflower. Journal of Soil and Nature 3(1):16-19.

Bailey D. S., Ferrarezi R. S., 2017 Valuation of vegetable crops produced in the UVI commercial aquaponic system. Aquaculture Reports 7:77-82.

Baker A., 2010 Preliminary development and evaluation of an aquaponic system for the American Insular Pacific. MSc thesis, University of Hawaii at Manoa, Honolulu, Hawaii, USA, 33 pp.

Blidariu F., Grozea A., 2011 Increasing the economical efficiency and sustainability of indoor fish farming by means of aquaponics - review. Scientific Papers: Animal Science and Biotechnologies 44(2):1-8.

Brodie L., 2021 Celery planting - vegetable farming in South Africa. Available at: https://southafrica.co.za/celery-planting.html. Accessed: November, 2021.

Burrows R., 2023 Fall frost tolerance of common vegetables. Available at: https://extension.sdstate.edu/fall-frost-tolerance-common-vegetables. Accessed: September, 2023.

Buzby K. M., Lin L. S., 2014 Scaling aquaponic systems: balancing plant uptake with fish output. Aquaculture Engineering 63:39-44.

Chitwood J., 2016 Spinach (*Spinacia oleracea* L.) seed germination and whole plant growth response to heat stress and association mapping of bolting, tallness and erectness for use in spinach breeding. Graduate theses and dissertations, University of Arkansas, Fayetteville, 63 pp.

Combs M. H., Ernst M., 2019 Celery and celeriac. University of Kentucky College of Agriculture, Food and Environment, CCDCP-92, Lexington, KY, 3 pp

Department of Agriculture, Forestry and Fisheries (DAFF), 2010 Spinach. Available at: http://www.dalrrd.gov.za/phocadownloadpap/Brochures_and_Production_Guidelines/Brochure%20Spinach.pdf. Accessed: January, 2021.

Department of Agriculture, Land Reform and Rural Development (DALRRD), 2015-2020 Statistics on fresh produce market. Available at: https://old.dalrrd.gov.za/Home/Crop-Estimates/Statistical-Information/Fresh-Produce. Accessed: January, 2021.

Danner R. I., Mankasingh U., Anamthawat-Jonsson K., Thorarinsdottir R. I., 2019 Designing aquaponic production systems towards integration into greenhouse farming. Water 11(10):2123.

De Beurs K. M., Brown M. E., 2013 The effect of agricultural growing season change on market prices in Africa. InTech. doi: 10.57.72/56459.

Dediu L., Cristea V., Xiaoshuan Z., 2012 Waste production and valorization in an integrated aquaponic system with bester and lettuce. African Journal of Biotechnology 11(9):2349-2358.

Delaide B., Delhaye G., Dermience M., Gott J., Soyeurt H., Jijakli M. H., 2017 Plant and fish production performance, nutrient mass balances, energy and water use of the PAFF Box, a small-scale aquaponic system. Aquaculture Engineering 78:130-139.

Demeke M., Pangrazio G., Maetz M., 2009 Country responses to the food security crisis: nature and preliminary implications of the policies pursued. FAO, Rome, 31 pp.
Diver S., 2006 Aquaponics - integration of hydroponics with aquaculture. A Publication of ATTRA - National Sustainable Agriculture Information Service, 28 pp.
Effendi H., Utomo B. A., Darmawangsa G. M., 2015 Phytoremediation of freshwater crayfish (*Cherax quadricarinatus*) culture wastewater with spinach (*Ipomoea aquatica*) in aquaponic system. AACL Bioflux 8(3):421-430.
Endut A., Jusoh A., Ali N., Wan Nik W. B., 2011 Nutrient removal from aquaculture wastewater by vegetable production in aquaponic recirculation system. Desalination and Water Treatment 32:422-430.
Estim A., Saufie S., Mustafa S., 2019 Water quality remediation using aquaponics sub-systems as biological and mechanical filters in aquaculture. Journal of Water Process Engineering 30:100566.
FAO, 2017 The future of food and agriculture: trends and challenges. FAO, Rome, 163 pp.
FAO, IFAD, IMF, OECD, UNCTAD, WFP, the World Bank, the WTO, IFPRI, the UN HLTF, 2011 Price volatility in food and agricultural markets: policy responses. Policy report, 67 pp.
Fatima A., Abid S., Naheed S., 2015 Trends in wholesale prices of onion and potato in major markets of Pakistan: a time series analysis. Pakistan Journal of Agricultural Research 28(2):152-158.
Ferrarezi R. S., Bailey D. S., 2019 Basil performance evaluation in aquaponics. HortTechnology 29(1):85-93.
Fourie L. J., 2010 The mathematical formulation and scheduling for creating a self sustainable vegetable food garden. BSc Thesis, University Pretoria.
Gambelli D., Vairo D., Solfanelli F., Zanoli R., 2019 Economic performance of organic aquaculture: a systematic review. Marine Policy 108:103542.
Geisenhoff L. O., Jordan R. A., Santos R. C., de Oliveira F. C., Gomes E. P., 2016 Effect of different substrates in aquaponic lettuce production associated with intensive tilapia farming with water recirculation systems. Journal of the Brazilian Association of Agricultural Engineering 36(2):291-299.
Gosh K., Chowdhury S., 2019 Review of aquaponics system: searching for a technically feasible and economically profitable aquaponics system. Journal of Agricultural, Environmental and Consumer Sciences 19:5-13.
Graber A., Junge R., 2009 Aquaponic systems: nutrient recycling from fish wastewater by vegetable production. Desalination 246(1-3):147-156.
Groom B., Tak M., 2013 Welfare analysis of changing food prices: a nonparametric examination of export ban on rice in India. Working Papers 177, Department of Economics, SOAS University of London, UK, 33 pp.
Hagos B. G., Hadush M., 2016 Price effect of climate change on vegetable crops: evidence from Tigrai, Northern Most Ethiopia. Civil and Environmental Research 8(9):104-123.
Hasan N. A., 2014 Aquaponics system for treat a catfish wastewater. BSc thesis, University Malaysia Pahang, 38 pp.
Hoffmann W. H., Harrison K., 2018 Overview of the vegetable industry of the Western Cape. Available at: http://www.elsenburg.com/sites/default/files/Annexure%20C%20%20Vegetable%20Production%20Overview%20in%20South%20Africa%2C%20Western%20Cape%20and%20PHA_0.pdf. Accessed: January, 2023.
Hossain M. F., Ara N., Uddin M. R., Uddin M. S., Islam M. R., 2014 Response of sowing date on seed production of cauliflower. Bangladesh Journal of Agriculture and Environment 10(1):20-23.
Hu Z., Lee J. W., Chandran K., Kim S., Brotto A. C., Khanal S. K., 2015 Effect of plant species on nitrogen recovery in aquaponics. Bioresource Technology 188:92-98.
Illankoon I. M. G. L., Kumara B. T. G. S., 2020 Analyzing the influence of various factors for vegetable price using data mining. 13th International Research Conference, General Sir John Kotelawala Defence University, pp. 402-409.

IPCC, 2012 Managing the risks of extreme events and disasters to advance climate change adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Field C. B., Barros V., Stocker T. F., Qin D., Dokken D. J., Ebi K. L., Mastrandrea M. D., Mach K. J., Plattner G. K., Allen S. K., Tignor M., Midgley P. M. (eds), Cambridge University Press, Cambridge, UK, 582 pp.
Johnson G. E., Buzby K. M., Semmens K. J., Waterland N. L., 2017 Year-round lettuce (*Lactuca sativa* L.) production in a flow-through aquaponic system. Journal of Agricultural Science 9(1):75-84.
Kim M. J., Moon Y., Tou J. C., Mou B., Waterland N. L., 2016 Nutritional value, bioactive compounds and health benefits of lettuce (*Lactuca sativa* L.). Journal of Food Composition and Analysis 49:19-34.
Klinger D., Naylor R., 2012 Searching for solutions in aquaculture: charting sustainable course. Annual Review of Environment and Resources 37:247-276.
Kom Z., Nethengwe N. S., Mpandeli N. S., Chikoore H., 2022 Determinants of small-scale farmers' choice and adaptive strategies in response to climatic shocks in Vhembe District, South Africa. GeoJournal 87:677-700.
Kopsa P., 2015 Aquaponics: practical thesis in Australia. BSc thesis, University of Applied Sciences, 54 pp.
Liu P., Ma J., 2015 The impact of the rise in vegetable prices on vegetable producer behavior – based on the survey of vegetable producers in Jiayu, Hubei Province. SHS Web of Conferences 17:01011.
Love D. C., Fry J. P., Li X., Hill E. S., Genello L., Semmens K., Thompson R. E., 2015 Commercial aquaponics production and profitability: findings from an international survey. Aquaculture 435:67-74.
Malhotra S. K., 2006 Celery. In: Handbook of herbs and spices. Volume 3. Woodhead Publishing Series in Food Science, Technology and Nutrition, pp. 317-336.
Mariod A. A., Saeed Mirghani M. E., Hussein I., 2017 *Cucumis sativus* cucumber. In: Unconventional oilseeds and oil sources. Academic Press, London, pp. 89-94.
Mbow C., Rosenzweig C., Barioni L. G., Benton T. G., Herrero M., Krishnapillai M., Liwenga E., Pradhan P., Rivera-Ferre M. G., Sapkota T., Tubiello F. N., Xu Y., 2019 Food security supplementary material. In: Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Shukla P. R., Skea J., Calvo Buendia E., Masson-Delmotte V., Pörtner H. O., Roberts D. C., Zhai P., Slade R., Connors S., van Diemen R., Ferrat M., Haughey E., Luz S., Neogi S., Pathak M., Petzold J., Portugal Pereira J., Vyas P., Huntley E., Kissick K., Belkacemi M., Malley J. (eds), 18 pp.
Mchunu N., Lagerwall G., Senzanje A., 2017 Food sovereignty for food security, aquaponics system as a potential method: a review. Journal of Aquaculture Research and Development 8:(7):1000497.
Mchunu N., Lagerwall G., Senzanje A., 2018 Aquaponics in South Africa: results of a national survey. Aquaculture Reports 12:12-19.
Medina M., Jayachandran K., Bhat M. G., Deoraj A., 2016 Assessing plant growth, water quality and economic effects from application of a plant-based aquafeed in a recirculating aquaponic system. Aquaculture International 24:415-427.
Murcia M. A., Jiménez-Monreal A. M., Gonzalez J., Martínez-Tomé M., 2020 Spinach. In: Nutritional composition and antioxidant properties of fruits and vegetables. Jaiswal A. K. (ed), Academic Press, pp. 181-195.
Nadia Z. M., Roy P., Salam M. A., 2019 Comparison of broccoli (*Brassica oleracea* var. *italica*) production in hydroponic and aquaponic systems in captive condition. Conference: Biennial Conference of Fisheries Society of Bangladesh (FSB) 2019.
Ninfali P., Angelino D., 2013 Nutritional and functional potential of *Beta vulgaris cicla* and *rubra*. Fitoterapia 89:188-199.
Olabanji M. F., Ndarana T., Davis N., 2021 Impact of climate change on crop production and potential adaptive measures in the Olifants catchment, South Africa. Climate 9(1):6.

Oladimeji S. A., Okomoda V. T., Olufeagba S. O., Solomon S. G., Abol-Munafi A. B., Alabi K. I., Ikhwanuddin M., Martins C. O., Umaru J., Hassan A., 2020 Aquaponics production of catfish and pumpkin: comparison with conventional production systems. Food Science and Nutrition 8(5):2307-2315.
Pang W., Kim Y. Y., Li X., Choi S. R., Wang Y., Sung C. K., et al, 2015 Anatomic characteristics associated with head splitting in cabbage (*Brassica oleracea* var. capitata L.). PLoS ONE 10(11):e0142202.
Petljak K., Zulauf K., Štulec I., Seuring S., Wagner R., 2018 Green supply chain management in food retailing: survey-based evidence in Croatia. Supply Chain Management: An International Journal 23(1):1-15.
Phuoc M. N., 2019 Production of cucumber (*Cucumis sativus* var. *conomon*) juice. Research on Crops 20(2):369-375.
Pinho S. M., Molinari D., de Mello G. L., Fitzsimmons K. M., Coelho Emerenciano M. G., 2017 Effluent from a biofloc technology (BFT) tilapia culture on the aquaponics production of different lettuce varieties. Ecological Engineering 103:146-153.
Qu C., Li H., Hao S., Zhang X., Yang W., 2017 The effects of the vegetable prices insurance on the fluctuation of price: based on Shanghai evidences. AIP Conference Proceedings 1890(1):040015.
Rakocy J. E., 2002 Aquaponics: vegetable hydroponics in recirculating systems. In: Recirculating aquaculture systems. 2nd edition. Timmons M. B., Ebeling J. M., Wheaton F. W., Summerfelt S. T., Vinci B. J. (eds), Cayuga Aqua Ventures, Ithaca, New York, pp. 631-672.
Rakocy J. E., Shultz R. C., Bailey D. S., Thoman E. S., 2003 Aquaponic production of tilapia and basil: comparing a batch and staggered cropping system. Acta Horticulturae 648: South Pacific Soilless Culture Conference - SPSCC, pp. 63-69.
Rakocy J. E., Bailey D. S., Shultz R. C., Thoman E. S., 2004 Update on tilapia and vegetable production in the UVI aquaponic system. New dimensions on farmed tilapia. In: Proceedings of the Sixth International Symposium on Tilapia in Aquaculture, Manila, Philippines, pp. 676-690.
Ray M., Mishra N., 2017 Effect of weather parameters on the growth and yield of cauliflower. Environment Conservation Journal 18(3):9-19.
Reddy J., 2020a Growing beetroot hydroponically - a full guide. Gardening tips. Available at: https://gardeningtips.in/growing-beetroot-hydroponically-a-full-guide# Temperature_and_Lighting_for_Growing_Beetroot_hydroponically. Accessed: May, 2021.
Reddy J., 2020b Hydroponic spinach farming. Gardening tips. Available at: https://www.agrifarming.in/hydroponic-spinach-farming-growing-tips. Accessed: June, 2021.
Resh H. M., 2012 Hydroponic food production: a definitive guidebook for the advanced home gardener and the commercial hydroponic grower. 7th edition. CRC Press, Boca Raton, FL, 560 pp.
Roosta H. R., 2014 Effects of foliar spray of K on mint, radish, parsley and coriander plants in aquaponic system. Journal of Plant Nutrition 37(14):2236-2254.
Roosta H. R., Hamidpour M., 2011 Effects of foliar application of some macro and micronutrients on tomato plants in aquaponic and hydroponic systems. Scientia Horticulturae 129:396-402.
Roosta H. R., Mohsenian Y., 2012 Effects of foliar spray of different Fe sources on pepper (*Capsicum annum* L.) plants in aquaponic system. Scientia Horticulturae 146:182-191.
Sace C. F., Fitzsimmons K. M., 2013 Vegetable production in a recirculating aquaponic system using Nile tilapia (*Oreochromis niloticus*) with and without freshwater prawn (*Macrobrachium rosenbergii*). Academia Journal of Agricultural Research 1(12): 236-250.
Sala F. C., da Costa C. P., 2012 [Retrospective and trends of Brazilian lettuce crop]. Horticultura Brasileira 30(2):187-194. [in Portuguese]
Saufie S., Estim A., Shaleh S. R. M., Mustafa S., 2020 Production efficiency of green beans integrated with tilapia in a circular farming system of media-filled aquaponics. Spanish Journal of Agricultural Research 18(3):e0611.

Savidov N., Hutchings E., Rakocy J. E., 2007 Fish and plant production in a recirculating aquaponic system: a new approach to sustainable agriculture in Canada. Acta Horticulturae 742:209-222.
Schiller N., 2022 How to grow cauliflower, a challenging cool-weather crop. Gardener's path. Available at: https://gardenerspath.com/plants/vegetables/how-to-grow-cauliflower-a-challenging-cold-weather-crop/. Accessed: January, 2021.
Seaman A., 2016 Production guide for organic spinach. New York State Integrated Pest Management Program, Cornell University (New York State Agricultural Experiment Station, Geneva, NY), 50 pp.
Sherrick B., 2012 Relative importance of price vs. yield variability in crop revenue risk. Farmdoc Daily (2):198, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign.
Shete A. P., Verma A. K., Tandel R. S., Prakash C., Tiwari V. K., Hussain T., 2013 Optimization of water circulation period for the culture of goldfish with spinach in aquaponic system. Journal of Agricultural Science 5(4):26-30.
Short G., Yue C., Abbey M., Anderson N., Phelps N., Venturelli P., Vickers Z., 2018 Consumer preferences for aquaponic produce: implications from an experimental auction. Agribusiness 34(4):1-14.
Silva J. V., Baudron F., Reidsma P., Giller K. E., 2019 Is labour a major determinant of yield gaps in sub-Saharan Africa? A study of cereal-based production systems in Southern Ethiopia. Agricultural Systems 174:39-51.
Simeonidou M., Paschos I., Gouva E., Kolygas M., Perdikaris C., 2012 Performance of a small-scale modular aquaponic system. AACL Bioflux 5(4):182-188.
Skar S. L. G., Liltved H., Kledal P. R., Høgberget R., Björnsdottir R., Homme J. M., Oddsson S., Paulsen H., Drengstig A., Savidov N., Seljåsen R., 2015 Aquaponics NOMA: new innovations for sustainable aquaculture in the Nordic countries. Nordic Innovation, Stensberggata, 107 pp.
Somerville C., Cohen M., Pantanella E., Stankus A., Lovatelli A., 2014 Small-scale aquaponic food production. Integrated fish and plant farming. FAO Fisheries and Aquaculture Technical Paper No. 589, FAO, Rome, 262 pp.
Sowing Chart – South Africa, 2014 Available at: https://www.sowdelicious.co.za/sowing-chart/. Accessed: July, 2021.
Spiro J., 2016 Seasonal fruit and vegetable chart for South Africa. Available at: https://crushmag-online.com/seasonal-fruit-vegetable-chart-south-africa/. Accessed: March, 2021.
Starke Ayres, 2019a Cauliflower production guideline. Available at: https://www.starkeayres.com/uploads/files/Cauliflower-Production-Guideline-2019.pdf. Accessed: January, 2021.
Starke Ayres, 2019b Beetroot production guideline. Available at: https://www.starkeayres.com/uploads/files/Beetroot-Production-Guideline-2019.pdf. Accessed: February, 2021.
Starke Ayres, 2019c Eggplant production guideline. Available at: https://www.starkeayres.com/uploads/files/Eggplant-Production-Guideline-2019.pdf. Accessed: February, 2021.
Starke Ayres, 2019d Sowing guide: flower, vegetable, lawn and herb seed. Available at: www.Starkeayres.co.za. Accessed: February, 2021.
Thorarinsdottir R., Kledal P. R., Skar S. L. G., Sustaeta F., Ragnarsdottir K. V., Mankasingh U., Pantanella E., van de Ven R., Shultz C., 2015 Aquaponics guidelines. University of Iceland, Reykjavik, Iceland, 63 pp.
Tokunaga K., Tamaru C., Ako H., Leung P. S., 2015 Economics of small-scale commercial aquaponics in Hawai'i. Journal of the World Aquaculture Society 46(1):20-32.
Trang N. T. D., Schierup H. H., Brix H., 2010 Leaf vegetables for use in integrated hydroponics and aquaculture systems: effects of root flooding on growth, mineral composition and nutrient uptake. African Journal Biotechnology 9(27):4186-4196.
Tyson R. V., Simonne E. H., Treadwell D. D., 2008 Reconciling pH for ammonia biofiltration and cucumber yield in a recirculating aquaponic system with perlite biofilters. HortScience 43(3):719-724.

Tyson R. V., Treadwell D. D., Simonne E. H., 2011 Opportunities and challenges to sustainability in aquaponic systems. HortTechnology 21(1):6-13.
Verdegem M. C. J., 2013 Nutrient discharge from aquaculture operations in function of system design and production environment. Reviews in Aquaculture 5(3):158-171.
Wahyuningsih S., Effendi H., Wardiatno Y., 2015 Nitrogen removal of aquaculture wastewater in aquaponic recirculation system. AACL Bioflux 8(4):491-499.
Wirza R., Nazir S., 2020 Urban aquaponics farming and cities - a systematic literature review. Reviews on Environmental Health 36(1):47-61.
World Bank Group, 2021 Commodity markets outlook: causes and consequences of metal price shocks. April 2021. World Bank, Washington, DC, 87 pp.
Yildiz H. Y., Robaina L., Pirhonen J., Mente E., Domínguez D., Parisi G., 2017 Fish welfare in aquaponic systems: its relation to water quality with an emphasis on feed and faeces - a review. Water 9(1):13.
Zou Y., Hu Z., Zhang J., Xie H., Guimbaud C., Fang Y., 2016 Effects of pH on nitrogen transformations in media-based aquaponics. Bioresource Technology 210:81-87.

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