Agronomic characteristics and nutritional quality of carrot (*Daucus carota* L.) cultivars from Myanmar and Germany as affected by mineral and organic fertilizers

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List of acronyms and abbreviations

µl	microliter
µm	micrometer
µM	micromole
µg	microgram
ANOVA	analysis of variance
AVRDC	Asian Vegetable Research and Development Centre
C:N	carbon nitrogen ratio
Ca	calcium
CAL	calcium-acetate-lactate extracting solution
CM	compost manure
CM-L1	Compost at N 60 kg ha^{-1}
CM-L2	Compost at N 120 kg ha^{-1}
CM-L3	Compost at N 180 kg ha^{-1}
Cu	copper
cv	cultivar
cvs.	cultivars
DIP	2,6-di-chlorphenolindophenol
Fe	iron
FM	farmyard manure
FM-L1	FYM at N 60 kg ha^{-1}
FM-L2	FYM at N 120 kg ha^{-1}
FM-L3	FYM at N 180 kg ha^{-1}
FRAP	Ferric Reducing Antioxidant Power
FW	Fresh weight
g	gram
H_2O_2	hydrogen peroxide
ha	hectare
HNO_3	nitric acid
HPLC	high performance liquid chromatography

IPGRI	International Plant Genetic Resources Institute
ISTA	International Seed Testing Association
K	potassium
KCl	potassium chloride
kg	kilogram
KH_2PO_4	potassium dihydrogen phosphate
MAS	Myanmar Agriculture Service
MF	mineral fertilizer
MF-L1	mineral fertilization with N 60 kg ha^{-1}
MF-L2	mineral fertilization with N 120 kg ha^{-1}
MF-L3	mineral fertilization with N 180 kg ha^{-1}
Mg	magnesium
mg	milligram
ml	milliliter
mm	milimeter
mM	milimole
Mn	manganese
N	nitrogen
NH_4NO_3	ammonium nitrate
ºC	degree Celsius
P	phosphorous
PCARRD	Philippine council for agriculture, forestry and natural resources research and development
RAE	retinol activity equivalents
RDA	recommended dietary allowance
rpm	revolutions per minute
SD	standard deviation
SE	standard error
t	tonne
TSS	total soluble solids
USDA	United States Department of Agriculture
Zn	zinc

1. General introduction

1.1. Background

Carrot is the second most important vegetable in Germany and the quantity sold is about 547073 t year^{-1} (FAO 2008) with an annual consumption of seven kg per person (Habegger and Graβmann 2007). World total production is about 27.39 million t in the year 2008. The average yield in Germany is 53.5 t ha^{-1} and in the world it is 22.41 t ha^{-1} (FAO 2008).

In Myanmar, carrot can be grown in upland areas like Shan State and Pyin Oo Lwin throughout the year and in lowlands it can be grown only in the winter season. The average yield of carrot in Myanmar is 5 to 12 t ha^{-1}, quite low as compared to world average (MAS 2007). There are three major categories of constraints that hamper the vegetable production intropical developing countries: environmental, technical and socioeconomic restrictions. Depending on the nature of the crop and circumstances, the solutions to overcome these constraints will be different (AVRDC 1997).

Generally, in Myanmar, as a part of the traditional cropping systems in highlands, farmers usually keep carrot seeds from their own crops for the next planting year after year. The advantage of using local cultivars is that they are well adapted to adverse environmental conditions and relatively resistant to pests and pathogens. Moreover, carrots are grown using organic manure which is cheap and readily available within the vicinity of the farms. As a consequence, crop yield is low, and hence, growers turn to use improved hybrid cultivars which can ensure higher yield and quality. Hybrids are basically of improved plant morphology, e.g. better root system or leaf canopy, which stress efficient uptake of mineral nutrients (Fageria *et al*. 2008; Mengel 1983).

Usually farmers use fertilizers in order to get high yield. Therefore it is necessary to apply the fertilizer in adequate amounts which might also be able to adjust balance between nutrients. For example, use of N fertilizers might have beneficial effect on carrot yield, however, if applied in abundant amount, higher nitrate might accumulate in carrot (Cserni *et al.* 1989). Leaching and runoff could also have adverse effects on the environment, or nutrient imbalance might lead to deficiency of other cations (Biegon 1995). Hybrid cultivars with high harvest index are sometimes better in nutrient use efficiency, i.e higher yield per unit of nutrient uptake and they may perform better than traditional cultivars under stress conditions including low-input conditions (Vose 1990; Inthapanyaa *et al.* 2000). Therefore, information about yield and quality of the local and hybrid carrot cultivars in response to the different fertilizer types would be a useful knowledge especially to the farmers in Myanmar.

1.2. Literature review

1.2.1. Carrot origin and characteristics

Carrot is the one of the major vegetable crops cultivated worldwide (Rubatzky *et al.* 1999). The domesticated types are divided into two groups: (1) the Eastern or Asian carrots (var. *atrorubens* Alef.), with mainly purple and yellow roots; and (2) the Western carrots [var. *sativus* (Hoffm.) Arcangeli] with mainly orange roots. Carrots were thought to be domesticated in Afghanistan as the primary centre of diversity and they were spread over Europe, Asia and the Mediterranean area, and the origin of western cultivated carrots were thought to be in the Asia Minor Centre, primarily Turky (Simon 1996; Rubatzky *et al.* 1999). The origins of cultivated carrots are shown in Table 1-1.

Table 1-1 Origins of the cultivated carrots

Time	Location	Colour
Pre-900s	Afghanistan and vicinity	Purple and yellow
900s	Iran and northern Arabia	
1000s	Syria and North Africa	
1100s	Spain	
1200-1300	Italy and China	
1300s	France, Germany and The Netherlands	
1400s	England	
1600s	Japan	
1600s	Northern Europe and North America	Orange and white
1700s	Japan	Orange
1721	Northern Europe	'Long Orange' and 'Horn' types described

Source: Rubatzky *et al.* (1999)

From the first cultivated purple or violet carrots, yellow and orange types were derived from this anthocyanin type by selection process (Banga 1984). Traditionally, purple carrots are still grown in some oriental countries such as Turkey, Afghanistan, Egypt, Pakistan, India and the Far East. Nowadays, purple and yellow - coloured cvs.

appeared in the European market and in fact they are bred from Asian lines (Simon 2000; Rubatzky *et al*. 1999).

The colour of carrot root is the result of various pigments that serve as intermediate products in the carotenoids pathway (Koch and Goldman 2005). Six carotenes have been reported in carrots, as α-, β-, γ- and ξ-carotenes, lycopene and β-zeacarotene (Simon and Wolff 1987). The major pigments responsible for orange and yellow colour of the roots are α- and β-carotene. β-carotene often represent 50% or more of the total carotenoids content. The red colour of the carrot root is caused by lycopene and the yellow colour is affected by xanthophylls (Rubatzky *et al.* 1999). White roots are low in total carotenoids (Buishand and Gableman 1979).

Purple carrots contain very high contents of phenolics, mainly anthocyanins, and are characterized by a higher antioxidant capacity than orange, yellow or white varieties (Alasalvar *et al*. 2005). Differences in chemical composition, mainly among the phenolics, have been demonstrated as useful in distinguishing some *Daucus* species, whereas polyacetylenes, coumarins and sugars have not provided useful distinction (Crowden *et al.*1969).

1.2.2. Carrot quality

Consumers' choice to eat carrots is often based on perceptions of carrots quality that include organoleptic, sensory and nutritional factors (Rubatzky *et al.* 1999). Carrots are increasing consumed due to their quality characteristics such as flavour compounds, sugars, dry matter (DM) contents and their perceived health benefits related to their vitamins, minerals, and fiber (Alasalvar *et al.* 2001; Quilitzsch *et al.* 2005). The United States Department of Agriculture (USDA) National Nutrient Database for Standard Reference (2010) offers nutrient compositions of carrot, based on 100 g fresh carrot and some of data are presented in Table 1-2.

Carrot quality is partly determined by its sugar content which contributes to sweetness (Simon *et al.* 1980). In carrot roots, the total sugar content ranges from 3.5 to 10.7% in fresh carrots (Alabran and Mabrouck 1973). Sucrose was the major sugar (representing 56.9% of total sugars), followed by glucose (24.6%) and fructose (18.5%) (Rodrıguez-Sevilla *et al.* 1999). About 30 and 70% of the DM content consists of soluble sugar (Kjellenberg 2007). Phenolics compounds together with other compounds can contribute to bitter taste in carrot (Kjellenberg 2007). Sweet and bitter taste in carrots is dependant on both genetic and environmental factors. Cultivar choice and cultural practices can therefore highly affect the taste of carrots before they reach the consumer.

At the time of harvest the carrot storage root consist of about 85 to 90% of water and 10-15% DM. The ash content is usually between 5 and 10% DM (Odebode and

Unachukwu 1997). The total organic acids contain 0.19% fresh weight (FW) and the most common organic acids in carrots are malic (0.08%), isocitric (0.10%) and citric acid (0.004%) (Phan *et al.* 1973).

Table 1-2 Nutritional composition of carrot: extract of data from USDA National Nutrient Database

Nutrient	Units	Value per 100 g FW
Proximates		
Protein	g	0.93
Carbohydrate, by difference		9.58
Fiber, total dietary		2.80
Sugars, total		4.74
Sucrose		3.59
Glucose		0.59
Fructose		0.55
Minerals		
Calcium	mg	33.00
Iron		0.30
Magnesium		12.00
Phosphorus		35.00
Potassium		320.00
Sodium		69.00
Zinc		0.24
Copper		0.05
Manganese		0.14
Vitamins		
Vitamin C, total ascorbic acid	mg	5.90
Thiamin		0.07
Riboflavin		0.06
Niacin		0.93
Vitamin B-6		0.14
Carotene, beta	µg	8285.00
Carotene, alpha		3477.00
Lycopene		1.00
Lutein + zeaxanthin		256.00
Vitamin E (alpha-tocopherol)		0.66
Vitamin K(phylloquinone)		13.20

Source: Retrived from http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl on April 2010

1.2.3. Efficacy of fertilizers on carrot productivity and quality

Application of organic manures have numerous beneficial effects, which not only increase the crop yield but also improve soil fertility in terms of organic carbon and nitrogen (N) content, permeability, balanced supply of nutrients, plant available water capacity and build up of organic matter. In addition, they are known to improve rhizosphere ecosystem, suppress soil-borne phytopathogens, promote root growth and increased micronutrient uptake (Keener *et al.* 2000; McSorly and Gallaher 1996; PCARRD 2006; Lithourgidis *et al.* 2007). However, it is necessary to apply the fertilizer in adequate amounts which might also be able to adjust balance between nutrients. The amount of fertilizer applied to carrot varies considerably depending upon many factors such as time of the year, sources or forms of nutrients, soil fertility and stress conditions (Rubatzky *et al.* 1999). However, efficient utilization of nutrients by crops from the applied organic materials might be challenging since the slow release of organic fertilizers often results in slow growth of crop compared to readily available mineral fertilizers.

Carrot yield and nutritional quality are affected by the types of fertilizer applied. Among the chemical constituents of the fertilizers, N plays a dominant role in affecting the nutritional quality (Kansal *et al.* 1981). Carrot root yield was improved by hundred percent recommended dose of N, phosphorous (P) and potassium (K) fertilizers compared to application of organic fertilizer alone or combined application of mineral and organic fertilizer (Rani and Mallareddy 2007). The most commonly used fertilizer levels were N which was ranged between 75 - 150 kg ha^{-1}, 25 - 125 kg ha^{-1} of P and 0 - 175 kg ha^{-1} of K (Rubatzky *et al.* 1999).

Adequate use of mineral fertilizers and organic manures is of great importance for obtaining high yield and quality of produce in one hand and on the other hand prevention of adverse effects on soil health and environment (Rani and Mallareddy 2007). However, there is a basic constraint in handling the organic fertilizers due to their bulkiness and slowly available nutrient compared to chemical fertilizers (Hailu *et al.* 2008). Furthermore, it is difficult to make precise recommendations for chemical fertilizers unless they are site specific since the reports for various fertilizer experiments are quite variable (Rubatzky *et al.* 2009).

Nitrogen fertilization has received most attention of researchers with regard to carrot quality (Hochmuth *et al.* 2006). Increased root yield applied by increased N levels were reported (Hochmuth *et al.* 1999; Hailu *et al.* 2008). However, high N rate up to 336 kg ha^{-1} increased the nitrate level above the recommended dose for baby food (Chessin and Hicks 1987; Cserni *et al.* 1989).

In tomato production, N from compost application led to significant lower yield than those of other N fertilizers and it was supposed that N in compost was not readily